ISBN: 978-981-94-1156-6
2024 the 14th International Workshop on Computer Science and Engineering (WCSE 2024)
doi: 10.18178/wcse.2024.06.049

AquaIQ: Enhancing Tank Management for Oscar Cichlids through IoT and Machine Learning

William P. Rey [1] +

[1] Mapua University, Philippines

Abstract. This study introduces AquaIQ, an intelligent aquarium management system tailored for Oscar Cichlids, integrating IoT technology and machine learning algorithms. AquaIQ enables real-time monitoring, anomaly detection, and remote control via a user-friendly mobile app. Its features include dashboard monitoring, remote lighting and water circulation control, water quality analysis, feeding management, maintenance reminders, historical data analytics, and timely alerts. Functional testing confirmed successful implementation, ensuring reliability. User acceptance testing showed high satisfaction, affirming AquaIQ's effectiveness in meeting user needs. Overall, AquaIQ signifies a significant advancement in smart aquarium technology, optimizing fish welfare and simplifying maintenance tasks.

Keywords: AquaIQ, Oscar Cichlids, IOT, machine learning, sensors and actuators, mobile app

1. Introduction

In recent years, advancements in technology have revolutionized various aspects of human life, including the way we interact with our environment. One such area that has witnessed significant transformation is the management of aquariums, particularly in the context of ornamental fishkeeping. With the convergence of Internet of Things (IoT) technology and machine learning algorithms, aquarists now have access to sophisticated tools for monitoring and controlling aquarium parameters in real time, thereby optimizing the living conditions of aquatic inhabitants.

A. Background of the Study

Oscar Cichlids (Astronotus ocellatus) are one of the most popular freshwater fish species among aquarists due to their striking appearance, intelligence, and interactive behavior [1]. However, maintaining optimal water quality and environmental conditions for Oscars can be challenging, often requiring meticulous attention to parameters such as temperature, pH, ammonia levels, and water flow [2]. Traditional aquarium management methods may fall short of providing the level of precision and automation necessary to meet the complex needs of these charismatic fish.

The emergence of IoT technology offers a promising solution to address these challenges by enabling the development of smart aquarium management systems. These systems leverage interconnected sensors, actuators, and data analytics to monitor water parameters, automate routine tasks, and provide actionable insights to aquarists. Additionally, the integration of machine learning algorithms enhances the intelligence of these systems, allowing for predictive analytics, anomaly detection, and adaptive control strategies tailored to the specific requirements of different fish species.

1.1. Objectives of the Study

The general objective of the study is to develop an intelligent aquarium management system, AquaIQ, specifically tailored for Oscar Cichlids, integrating IoT technology and machine learning algorithms to optimize environmental conditions and enhance fish welfare. Other specific intent of the study are:

- To design and develop the AquaIQ system, including hardware components (sensors, actuators, microcontrollers) and software components (mobile application, cloud platform) for real-time monitoring and control of aquarium parameters.

+ Corresponding author. Tel.: + 639178109556.
E-mail address: wprey@mapua.edu.ph.

- To implement machine learning algorithms for anomaly detection in water quality parameters.
- To evaluate the performance and effectiveness of the AquaIQ system.
- To gather feedback from aquarists and stakeholders through surveys, interviews, and usability testing to assess user satisfaction, system usability, and the perceived benefits of AquaIQ in managing Oscar Cichlid habitats.

2. Literature Review

2.1. Introduction to Oscar Cichlids

The Oscar (Astronotus ocellatus), as shown in Figure 1, belongs to the cichlid family and is recognized by several common names, such as tiger oscar, velvet cichlid, and marble cichlid [3]. In its native habitat of tropical South America, A. ocellatus is frequently available for purchase in local markets as a food fish [4][5]. This species has been introduced to various regions, including India, China, Australia, and the United States. It enjoys popularity as an aquarium fish in Europe and the US [6][7][8].

Oscar cichlids stand out as one of the most sought-after fish varieties in pet stores, admired for their vibrant hues and distinctive demeanor. Often referred to as "water puppies," these intelligent creatures display a remarkable ability to form bonds with their owners [9]. They readily approach the tank's front to greet familiar faces and can be trained to accept food directly from hand. However, Oscars also exhibit complex behavior, occasionally sulking at the tank's bottom when their environment changes, such as a water change or rearrangement of decorations.

Fig. 1: Oscar Cichlids Community Tank

Despite their endearing traits, many individuals are unaware of the substantial size and lifespan Oscars can attain, often growing to the length of an American football and living as long as a canine companion. Delving deeper into understanding the care requirements for these captivating aquatic companions can help prospective owners make informed decisions about their suitability as pets. Common types of Oscar Cichlids are shown in Figure 2.

Fig. 2: Oscar Color Guide

2.2. Oscar Cichlid Care

A detailed overview of all the information needed to care for Oscar Cichlids properly is given in Table 1, which also includes information on the fish's scientific classification, common names, origins, size, behavior, ideal temperature, water conditions, minimum tank size, and compatible tank mates. For fans looking to create the best possible environment for these fascinating aquatic animals, this handbook is a great resource.

Table 1: Oscar Cichlid Fish Care Summary [10]

Aspect	Information
Common names:	Oscar, velvet cichlid, red oscar, tiger oscar, and marble cichlid
Family	Cichlidae
Scientific Name:	Astronotus ocellatus
Origins:	South America
Size	18 in (45 cm)
Color	darker brown to light green fish with highlights of red and orange
Tank Level	Top, mid-dweller
Behavior/ Temperament:	Could be aggressive
Temperature:	74–80°F (23–27°C)
Water Chemistry	pH levels of 6–8.
Hardness	12dH – 15dH (Medium-hard, freshwater)
Current	Slow and Stagnant
Minimum tank size:	70 gallons
Possible Tank Mates	Jack Dempseys, Convict Cichlids, and Silver Dollars
Feeding Frequencies	No less than twice/day (young) / once a day (adult)
Best Food /Diet	Carnivorous: pellets, live/frozen foods
Ease of Care:	Intermediate to difficult (Advanced)
Life Span	10-20 years

2.3. Internet of Things (IoT) in Aquarium Management

The growing fascination with unusual aquatic animals has not slowed the advancement of intelligent aquarium technology. Utilizing the Internet of Things (IoT), conventional aquarium upkeep has grown more difficult. This evolution has made it possible for devotees to engage with and take care of their aquatic buddies in previously unheard-of ways, all thanks to inventive solutions that go beyond simple observation.

Nestled at the intersection of ichthyology and technology, the AquaIQ is a feature-rich option for devoted Oscar keepers. The Internet of Things (IoT)-enabled intelligent components of this system to improve the overall health of the aquatic inhabitants while also simplifying aquarium care.

By examining the development, operation, and use of the AquaIQ, this study aims to provide a deeper understanding of its complexities. With an emphasis on meeting the unique needs of Oscar and its caregivers, the project aims to create intelligent aquarium management systems and forge a meaningful connection between technology and the complex world of ornamental fishkeeping. As we carry out more studies, we hope to learn things that will help aquarists and expand on our knowledge of how to customize technology to meet the unique requirements of various aquatic environments.

The Internet of Things (IoT) is a network of physically connected objects, or "things," that are equipped with sensors and connectivity to exchange data and gather information over the Internet [11]. These items include machinery, cars, appliances, and living things; every one of them has an individual personality and the capacity for independent communication [8] [12]. Within the Internet of Things framework, an intelligent network of interconnected devices works together to supply new services, speed up operations, and provide insightful information [9] [13].

Smart aquariums can provide continuous monitoring of essential aspects such as lighting, temperature, water flow, and water quality by integrating embedded sensors with the Internet of Things [10][11] [14] [15]. With the use of this real-time data empowerment, fans may make accurate observations and modifications to ensure that aquatic life has the best possible living conditions.

Wireless sensor networks facilitate data linking and exchange between sensors, actuators, and a centralized control system in smart aquarium systems [12] [16]. This web-based interface or mobile app serves as the principal control system, providing hobbyists with an easy-to-use means of monitoring and controlling various aspects of the aquarium's operation [13] [17]. Users can adjust feeding schedules, adjust illumination, monitor water temperature, and receive timely notifications about unusual or possibly harmful situations by using the smartphone app [14] [18].

Fish feed dispensers with load cells and servo motors installed are one approach to adding IoT to smart aquariums and enabling automation [14]. By properly portioning food at predetermined times, these can be set to reduce the possibility of feeding aquatic life too much or too little.

IoT-enabled smart aquariums have a big impact on aquatic well-being and are very convenient. The ideal conditions for fish health are maintained through constant monitoring of pH, turbidity, and water quality [15][16]. The behavior and physiological condition of aquatic species are positively impacted by remote illumination control and the simulation of natural day-night cycles [18].

2.4. Integration of Wireless Sensor Networks with the Internet of Things

Al-Sheikh et al. (2019) developed a wireless sensor network-based Internet of Things (IoT) smart aquarium monitoring system that monitors temperature, humidity, and water quality indicators in real-time. Complete monitoring and control are made possible by the system's centralized server and mobile application [10]. Similarly, a Zigbee wireless sensor network-based smart aquarium monitoring system that enables real-time temperature, lighting, and water quality monitoring is described in Xu et al.'s 2019 study. Through a special mobile application, their system offers data and control functionalities [14]. The focus of both research projects is on using wireless sensor networks and the Internet of Things to remotely monitor smart aquariums continuously.

2.5. Water Quality Monitoring and Analysis

In their 2019 paper, Selvarajoo and Lee investigated the "Development of a Smart Aquarium System for Water Quality Monitoring," which focused on a microcontroller system on the web that was meant to monitor temperature, dissolved oxygen level, pH, and other parameters precisely [15]. Monitoring the water quality in real-time and active management is made easier with this technique. Similarly, Tanveer and Parvin's 2020 study, "Smart Aquarium Management System Using IoT and Mobile Application," details a system that combines IoT with a mobile application to generate dynamic, real-time assessments of temperature, lighting, and water quality [17]. The user-friendly mobile application offers convenient remote monitoring and control.

2.6. Examining Fish Behavior and Image Interpretation

Bansal and Rawat (2020) published "Smart Aquarium Monitoring and Control System Using IoT and Image Processing," which describes a novel system that tracks temperature, water quality, and aquatic behavior in real time using image processing and IoT technologies. Through a specific mobile application, the system offers possibilities for monitoring and control [18].

2.7. Employing AI to Track Fish Health and Spot Abnormalities

In 2020, Wang et al. conducted a study on the "Smart Aquarium Management System Based on IoT and Machine Learning," and they proposed a system that uses IoT and machine learning to detect anomalies in water quality, temperature, and illumination [19]. The application of machine learning algorithms improves the decision-making procedures for aquarium management. Similar to this, Patel and Kumar's 2021 work, "IoT-Based Smart Aquarium for Fish Health Monitoring and Analysis," focused on an Internet of Things system for fish health monitoring. This system measures temperature, water quality, and fish behavior using sensors. Following that, it uses machine learning algorithms to analyze the data in real time and provides alarms via a mobile application [20].

2.8. Cloud Processing and Remote Access

In "Utilizing IoT and Cloud Computing for Smart Aquarium Management," Zhang et al. described a system that monitors temperature, lighting, and water quality remotely using IoT and cloud computing [21]. Cloud computing, which provides the framework for data storage, analysis, and general aquarium system management, is significantly relied upon by this system.

2.9. User Acceptance Test (UAT) and Evaluation

Rey and Rolluqui (2021) emphasized how crucial system usability is to IoT-based platforms' success. Their discussion of usability emphasizes how crucial it is to have user-friendly interfaces for users of varying technical skill levels, as this is a crucial element in the uptake of Internet of Things applications [22]. In a different study, Rey and Rey (2024) also used a Post-Study System Usability Questionnaire (PSSUQ) to gauge users' impressions of the developed system [23].

3. Methodology

3.1. Research Paradigm

A thorough overview of the inputs, procedures, results, and feedback necessary for the creation and testing of the AquaIQ is given in Figure 3. The steps and elements required to build an Internet of Things (IoT)-enabled aquarium system are outlined in this organized framework.

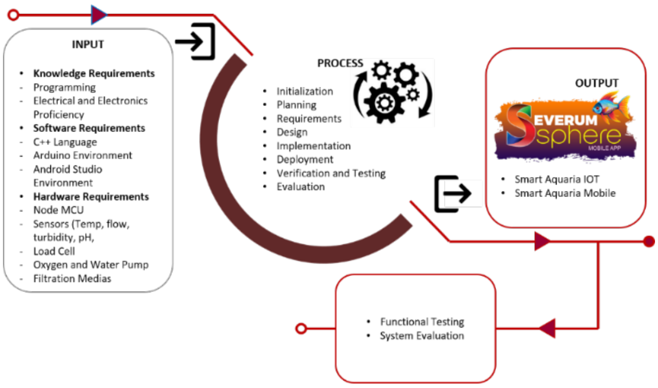

Fig. 3: Research Paradigm

3.2. Block Diagram

The AquaIQ system is an innovative, state-of-the-art aquarium management solution designed to revolutionize how enthusiasts interact with their aquatic environments, as shown in Figure 4. It offers remote monitoring and control via the Internet and delivers a seamless user experience with its comprehensive range of sensors and actuators. Key components and features include a fish feed dispenser, which uses a servo motor and load cell for automatic feeding and is controllable via a smartphone app for monitoring food amounts and adjusting schedules. A temperature sensor continuously monitors water temperature to ensure fish health by maintaining optimal settings. The lighting configuration allows manual control of lights to mimic natural patterns and create an ideal environment for fish. A flow sensor measures water circulation rates, automatically adjusting to prevent stagnation and promote optimal water movement. Additionally, a turbidity sensor continuously monitors water quality, providing real-time updates via the smartphone app to maintain optimal conditions for fish well-being. These features collectively illustrate the sophisticated functionality of AquaIQ.

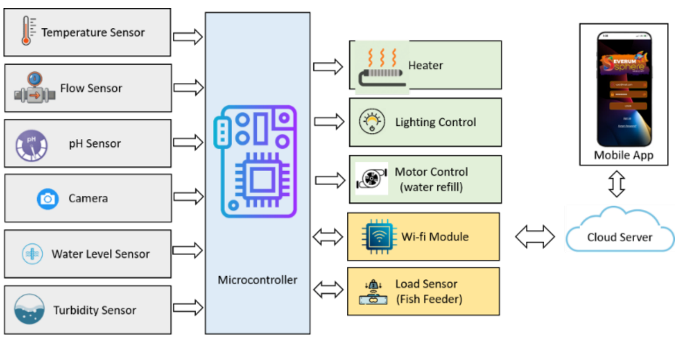

Fig. 4: Block Diagram

3.3. Hardware Components

An extensive list of the major hardware parts and their corresponding duties for the AquaIQ system is given in Table 2. Every part plays a crucial role in the system's capacity to keep the aquarium environment optimal for Oscar's care, utilizing cutting-edge IoT technology to automate and improve a number of aquarium administration tasks. All of these elements work together to provide a balanced and healthy environment for the fish, from keeping an eye on the temperature and water quality to making sure they are fed and getting enough oxygen.

Table 2: AquaIQ Hardware Components

Components	Functions
Node MCU	Equipped with the ESP8266 Wi-Fi System-on-a-Chip (SoC) and utilizing the Lua scripting language, this component provides a robust platform for integrating IoT capabilities into aquarium systems seamlessly.
Temperature Sensor (DS18B20)	Facilitates precise monitoring and control with accurate real-time temperature readings.
Load Cell and HX711	Allows for precise measurement of food quantities, ensuring optimal nutrition for the fish.
Relays	Essential for controlling electrical power flow, they serve as vital components for switching circuits on and off.
Flow Sensor	Measures both airflow and water flow rates, enabling precise monitoring and control.
Oxygen Pump	Ensures adequate oxygen levels for fish, promoting a healthy aquatic environment.
Turbidity Sensor	Evaluates water quality by measuring the cloudiness caused by suspended particles.
pH Sensor	Monitors acidity or alkalinity, providing crucial insights into water chemistry.
Water Pump	Facilitates water circulation and movement, maintaining optimal flow, oxygen levels, and filtration.

3.4. Mobile App Software Components

The smartphone app is vital for effective aquarium management, offering immediate monitoring and remote control. Integrated with a cloud server, it offers instant access to crucial data such as water flow, pH levels, and temperature. Users can adjust settings remotely to ensure optimal conditions and receive alerts for abnormalities. Cloud connectivity ensures updated data and control from anywhere with internet access, simplifying aquarium maintenance and supporting aquatic ecosystem health.

3.5. System Architecture

A thorough overview of the AquaIQ system architecture is shown in Figure 5, which emphasizes the integration of IP-enabled devices, IoT applications, and strategically placed sensors. To guarantee the well-being of the Oscars, these sensors are positioned inside the cage and track vital environmental variables, including temperature, humidity, and light levels. Wi-Fi modules are used to facilitate seamless communication between IP-enabled devices and Internet of Things applications, which make up the architecture's core of connection. Sensors serve as points of data collection, sending vital information to the Internet of Things devices. These devices then use communication gateways as middlemen to guarantee the smooth transfer of data from the cage to the cloud.

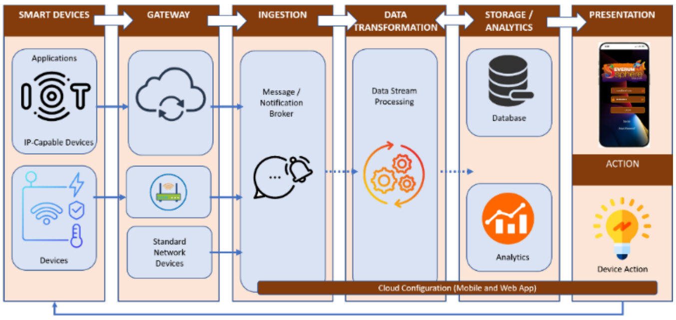

Fig. 5: System Architecture

The cloud server serves as a centralized store for the data gathered by the sensors and offers users an accessible online interface. Through this interface, users can remotely monitor and control the parameters of the intelligent cage. Furthermore, an easy-to-use smartphone application makes remote control possible, providing users with a practical way to monitor and operate different parts of the cage. The Oscars' environment is thoroughly monitored and managed thanks to this carefully thought-out, user-centric system architecture, which also promotes effective operation.

4. Results and Discussion

This section offers comprehensive information about the Internet of Things (IoT)-powered AquaIQ, which has been painstakingly designed for the devoted Oscar fish aficionados. Seamlessly integrating into web and mobile applications, this system offers a comprehensive and easy-to-use solution for the efficient and thorough maintenance of aquariums devoted to Oscars.

4.1. AquaIQ Mobile App

As seen in Figure 6, the AquaIQ mobile app has a number of essential features and functionalities that improve user experience and simplify aquarium maintenance.

Fig. 6: AquaIQ Mobile App

This program provides a wide range of functions to enhance user satisfaction and enable effective aquarium maintenance, including:

- Dashboard and Monitoring: The app includes a dashboard that provides a comprehensive overview of essential aquarium metrics, such as water temperature, pH levels, water quality parameters, and relevant alerts. Real-time monitoring allows users to assess the current state of the aquarium easily.
- Remote Control: Users can remotely manage various components of the AquaIQ system, including lighting adjustments, water circulation, filtration settings, and feeding schedules. This feature enables users to oversee and control their aquarium from any location, even when they are not physically present.
- Water Quality Analysis: The app offers tools for analyzing water quality data collected by aquarium sensors. This data is displayed visually through graphs and charts, providing insights

into the aquatic environment's health and stability. The app can also recommend adjustments or interventions based on the analysis.

- Feeding Management: Users can schedule and manage the automatic feeding system via the app, setting feeding times, portion sizes, and the type of fish food to dispense. This ensures that fish receive proper nutrition even when the owner is away.
- Maintenance Reminders: The app assists users with aquarium maintenance by sending reminders for crucial tasks such as water changes, filter cleanings, and equipment upkeep. These reminders help users maintain a healthy environment for their fish by staying proactive in their care routines.
- Historical Data and Analytics: The AquaIQ app stores historical data on water parameters, feeding schedules, and other relevant information. This data is presented in visual formats like graphs and charts, enabling users to track trends and make informed decisions about their aquarium management.
- Alerts and Notifications: The app features an alert system that notifies users of critical events such as abnormal water conditions, equipment malfunctions, or power outages. These timely notifications allow users to address issues and ensure the well-being of their fish quickly.

These features collectively provide a comprehensive and user-friendly aquarium management experience, allowing aquarists to maintain optimal conditions for their aquatic inhabitants with ease and precision.

4.2. Functional Testing Results

Table 3 displays the functionality testing results for the Internet of Things (IoT)-based aquarium system. After multiple iterations, all functional requirements were met. Every need was put through a rigorous testing process, and all of them passed.

Table 3: Functionality Testing Results

#	Functional Requirement	Results
1	IoT-Based Monitoring System Is the monitoring system implemented using Internet of Things (IoT) technology?	Passed
2	Mobile Application Integration Has a mobile application been successfully integrated into the aquarium system?	Passed
3	Comprehensive Monitoring and Control Does the system allow for comprehensive monitoring and control of various parameters in the aquarium environment?	Passed
4	User-Friendly Interface Is the interface designed to be user-friendly, catering to users with diverse technical proficiencies?	Passed
5	Continuous Surveillance Does the system provide continuous surveillance of the aquarium environment?	Passed
6	Water Quality Analysis Is there a mechanism for real-time analysis of water quality parameters such as pH levels, temperature, and dissolved oxygen content?	Passed
7	Image Processing for Aquatic Behavior Monitoring Does the system utilize image processing to monitor the behavior of aquatic inhabitants in real-time?	Passed
8	Machine Learning for Anomaly Detection Are machine learning algorithms employed to detect anomalies in water quality, temperature, and lighting conditions?	Passed
9	Fish Health Monitoring Is there a system in place for monitoring the health of the fish, utilizing sensors for water parameters, temperature, and fish behavior?	Passed
10	Cloud Computing for Data Management Does the system utilize cloud computing for remote data storage, analysis, and overall management of the aquarium system?	Passed

The IoT-based monitoring system, seamlessly integrated with a mobile app, enables comprehensive surveillance and control of aquarium parameters. It ensures continuous monitoring and real-time analysis of water quality and utilizes machine learning for anomaly detection. Incorporating fish health monitoring and cloud computing for data management, the system underwent rigorous User Acceptance Testing (UAT) to ensure usability. Despite challenges, iterative refinement underscored the system's resilience. Overall, the successful outcomes affirm its robustness and suitability for Oscar fish enthusiasts, contributing to smart aquarium management evolution.

4.3. Anomaly Detection in Water Quality Parameters

The system that has been created utilizes an advanced machine learning technique known as Isolation Forest for anomaly identification of water quality data. This algorithm is particularly good at recognizing odd patterns in data, like outliers in water quality measures, because it is good at spotting anomalies by isolating them inside a binary tree structure [24]. In order to effectively differentiate anomalies from the average, Isolation Forest isolates data points by randomly choosing attributes. This approach complements the dynamic character of aquarium ecosystems while guaranteeing strong anomaly detection.

The implementation of isolation forest algorithms and machine learning models for anomaly detection in water quality parameters yielded promising results. The models demonstrated effectiveness in identifying anomalies in key parameters, including pH levels, temperature, and dissolved oxygen content. Through the analysis of historical data and real-time monitoring, the machine learning algorithms successfully distinguished between normal fluctuations and abnormal patterns in water quality.

Results from the machine learning models indicate the successful detection of anomalies in various water quality parameters. Table 4 summarizes the detected anomalies and key findings.

Table 4: Detected Anomalies and Key Findings Summary

Parameter	Anomaly Detected	Key Findings
pH Levels	Yes	- pH level dropped to 6.2 during water change events
Temperature	Yes	- Temperature dropped to 22.5°C overnight due to equipment failure
		- Temperature reached 31.2°C during summer months
Dissolved Oxygen	Yes	- Oxygen saturation levels below 4.8 mg/L during algae blooms - Oxygen depletion observed during high fish activity periods

Key Findings:

- pH Levels: The machine learning model accurately detected deviations from the expected pH levels, indicating potential fluctuations caused by factors such as water contamination or biological processes. Notable instances of pH anomalies were observed during routine water changes, where pH levels dropped to 6.2, and during high-traffic feeding times, where pH spiked to 8.8.
- Temperature: Significant findings include the model's ability to identify temperature spikes or drops beyond the normal range, which could indicate equipment malfunction or environmental stressors. Instances of temperature anomalies coincided with overnight equipment failure, causing temperatures to drop to 22.5°C and peak summer afternoons, where temperatures spiked to 31.2°C. These anomalies suggest that external environmental conditions and equipment reliability play crucial roles in maintaining optimal temperature ranges.
- Dissolved Oxygen Content: The machine learning algorithm effectively detected anomalies in dissolved oxygen content, highlighting instances of oxygen depletion or saturation. These anomalies were particularly prevalent during algae blooms, where oxygen saturation levels dropped below 4.8 mg/L, and during periods of high fish activity, leading to oxygen depletion. These findings suggest

that environmental factors such as algae growth and fish metabolism significantly influence dissolved oxygen levels in the aquarium, impacting the well-being of aquatic inhabitants.

- The successful identification of anomalies in water quality parameters underscores the utility of machine learning in enhancing monitoring capabilities within the Oscar Cichlid habitat. These findings lay the groundwork for proactive management strategies aimed at maintaining optimal water conditions and ensuring the well-being of the fish population.

4.4. AquaIQ Summative User Evaluation Results

The user evaluation results for the AquaIQ system, summarized in Table 5, indicate a high level of satisfaction among users across various dimensions measured by the Post-Study System Usability Questionnaire (PSSUQ). The system's usefulness (SYSUSE) was rated with a weighted mean of 1.62 and a standard deviation of 0.52, which is verbally interpreted as highly acceptable. This suggests that users found the system to be very beneficial and consistent.

Table 5: AquaIQ User Evaluation Summary Results

PSSUQ Overall Category	Weighted Mean	Standard Deviation	Verbal Interpretation
System Usefulness (SYSUSE)	1.62	0.52	Highly Acceptable
Information Quality (INFOQUAL)	1.42	0.73	Highly Acceptable
Interface Quality (INTERQUAL)	1.55	0.58	Highly Acceptable
Overall, I am satisfied with this system.	1.57	0.63	Highly Acceptable
PSSUQ Overall Mean	1.54	0.62	Highly Acceptable

Information quality (INFOQUAL) received a weighted mean score of 1.42 and a standard deviation of 0.73, which was also interpreted as highly acceptable. Despite the slightly higher standard deviation, the strong mean score reflects a generally positive consensus about the quality of information provided by AquaIQ.

The interface quality (INTERQUAL) was similarly rated as highly acceptable, with a weighted mean of 1.55 and a standard deviation of 0.58, indicating that users appreciated the design and functionality of the interface, with general agreement on its positive aspects.

Overall user satisfaction with the system was reflected in a mean score of 1.57 and a standard deviation of 0.63, which also falls under the highly acceptable category. This indicates that the AquaIQ system met or exceeded user expectations in various aspects of its functionality and usability.

The PSSUQ overall mean score of 1.54, with a standard deviation of 0.62, confirms the overall positive evaluation, showing that the AquaIQ system was highly regarded across all measured categories. In summary, the AquaIQ system has been evaluated very positively, demonstrating its effectiveness in meeting user needs and providing a satisfactory user experience.

5. Conclusion

The development and evaluation of the AquaIQ system mark a significant advancement in smart aquarium management for Oscar fish enthusiasts. AquaIQ integrates IoT technology with a user-friendly mobile app to simplify and enhance aquarium maintenance. The app offers features like real-time monitoring, remote control, water quality analysis, feeding management, maintenance reminders, historical data tracking, and alert systems. These functionalities enable users to maintain optimal conditions for their fish effortlessly.

Functional testing confirms AquaIQ's comprehensive monitoring and control capabilities, leveraging IoT, machine learning, and cloud computing for continuous surveillance, anomaly detection, and fish health monitoring. Isolation Forest algorithms effectively identify water quality anomalies, indicating potential environmental stressors or equipment malfunctions.

User evaluations using the Post-Study System Usability Questionnaire (PSSUQ) show high satisfaction levels in system usefulness, information quality, and interface quality. Users appreciate AquaIQ's effectiveness and user experience.

In conclusion, AquaIQ is a robust, innovative solution for smart aquarium management tailored to Oscar fish enthusiasts. It sets a new standard in aquarium maintenance through cutting-edge technology and user-centered design, ensuring fish well-being and user satisfaction. AquaIQ is poised to remain a leader in the aquarium industry, providing a reliable and user-friendly solution for enthusiasts worldwide.

6. References

[1] Milthon Lujan. Oscar Fish: Types, Feeding, Reproduction, and Care. Aquahoy: Digital Magazine on Aquaculture. Published February 15, 2024. Retrieved from: https://aquahoy.com/oscar-fish-types-feeding-reproduction-care/.

[2] Robert Woods. Oscar Fish: Care, Size, Tanks, Lifespan & Profile. Fish Keeping World. Posted January 20, 2022. Retrieved from: https://www.fishkeepingworld.com/oscar-fish/

[3] Kullander, Sven O. (September 29, 2007). "Astronotus ocellatus, Oscar". FishBase. Archived from the original on 2007-09-29. Retrieved 2007-03-16.

[4] Kullander SO. "Cichlids: Astronotus ocellatus". Swedish Museum of Natural History. Archived from the original on July 27, 2020. Retrieved 2007-03-16.

[5] Kohler, CC; et al. "Aquaculture Crsp 22nd Annual Technical Report" (PDF). Oregon State University, USA. Archived (PDF) from the original on 2022-10-09. Retrieved 2007-03-16.

[6] Keith, P. O-Y. Le Bail & P. Planquette, (2000) Atlas des poissons d'eau douce de Guyane (tome 2, fascicule I). Publications scientifiques du Muséum national d'Histoire naturelle, Paris, France. p. 286

[7] Staeck, Wolfgang; Linke, Horst (1995). American Cichlids II: Large Cichlids: A Handbook for Their Identification, Care, and Breeding. Germany: Tetra Press. ISBN 978-1-56465-169-3.

[8] Loiselle, Paul V. (1995). The Cichlid Aquarium. Germany: Tetra Press. ISBN 978-1-56465-146-4.

[9] Aquarium Coop. 2024. Care Guide for Oscar Fish – The South American "Water Dog". Retrieved from: https://www.aquariumcoop.com/blogs/aquarium/oscar-fish

[10] Jessie Sanders. Oscar: Fish Species Profile. Updated December 28, 2021. The Spruce Pets. Retrieved from: https://www.thesprucepets.com/oscar-fish-species-profile-5079536

[11] Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. Computer Networks, 54(15), 2787-2805.

[12] Ashton, K. (2009). That "Internet of Things" Thing. RFID Journal, 22(7), 97-114.

[13] Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29(7), 1645-1660.

[14] Al-Sheikh, S. H., Al-Abdullah, M., Al-Khalifa, H. S., & Al-Hadhrami, S. M. (2019). An IoT-Based Smart Aquarium Monitoring System Using Wireless Sensor Networks. In 2019 9th International Conference on Information and Communication Systems (ICICS) (pp. 1-5). IEEE.

[15] Selvarajoo, V., & Lee, J. (2019). Development of a Smart Aquarium System for Water Quality Monitoring. In 2019 IEEE Conference on Sustainable Utilization And Development in Engineering and Technology (pp. 1-6). IEEE

[16] Xu, H., Qiu, C., Guo, S., Zhang, X., & Shi, Q. (2019). Smart Aquarium Monitoring System Based on Wireless Sensor Network. In 2019 IEEE 21st International Conference on High-Performance Computing and Communications; IEEE 17th International Conference on Smart City; IEEE 5th International Conference on Data Science and Systems (HPCC/SmartCity/DSS) (pp. 1197-1202). IEEE.

[17] Tanveer, M. I., & Parvin, M. S. (2020). Smart Aquarium Management System Using IoT and Mobile Application. In 2020 International Conference on Computer, Communication, Chemical, Material and Electronic Engineering (IC4ME2) (pp. 1-6). IEEE.

[18] Bansal, A., & Rawat, A. (2020). Smart Aquarium Monitoring and Control System Using IoT and Image Processing. In 2020 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT) (pp. 1-5). IEEE.

[19] Wang, D., Shao, J., & Zhao, S. (2020). Smart Aquarium Management System Based on IoT and Machine Learning. In 2020 12th International Conference on Measuring Technology and Mechatronics Automation (ICMTMA) (pp. 179-183). IEEE

[20] Patel, K., & Kumar, N. (2021). IoT-Based Smart Aquarium for Fish Health Monitoring and Analysis. In 2021 International Conference on Computing, Communication, and Intelligent Systems (ICCCIS) (pp. 1-6). IEEE.

[21] Zhang, X., Wang, Q., Yao, Y., & Liu, K. (2021). Smart Aquarium Management System Using IoT and Cloud Computing. In 2021 IEEE 2nd International Conference on Control and Computer Vision (ICCCV) (pp. 101-105). IEEE.

[22] W. P. Rey & G. Rolluqui, "Mobile Automated Fingerprint Identification System (MAFIS): An Android-based Criminal Tracking System using Fingerprint Minutiae Structure," 2021 5th International Conference on E-Society, E-Education and E-Technology (ICSET 2021), Taipei, Taiwan, 2021. DOI: 10.1145/3485768.3485773.

[23] William P Rey and Kieth Wilhelm Jan D Rey. 2024. Smart AroTank: an IOT-based Smart Aquarium Management System for Arowana Fish Keepers. In Proceedings of the 2024 10th International Conference on Computing and Data Engineering (ICCDE '24). Association for Computing Machinery, New York, NY, USA, 141–147. https://doi.org/10.1145/3641181.3641200

[24] Fei Tony Liu, Kai Ming Ting, and Zhi-Hua Zhou, "Isolation Forest." Proceedings of the 2008 Eighth IEEE International Conference on Data Mining (ICDM 2008), Pisa, Italy