ISBN: 978-981-94-1156-6
2024 the 14th International Workshop on Computer Science and Engineering (WCSE 2024)
doi: 10.18178/wcse.2024.06.044

Beyond the Tank: Next-Generation Aquaria for African Cichlid Fishkeeping

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Abstract. The integration of Internet of Things (IoT) technology into aquarium management systems has revolutionized the care and maintenance of aquatic habitats. This study presents "Beyond the Tank," a next-generation aquaria system specifically designed for African Cichlid Fishkeeping. Drawing on the popularity and unique requirements of African Cichlids, this research explores the development, implementation, and evaluation of an IoT-enabled solution aimed at enhancing fish management and welfare. The system incorporates a dedicated mobile application, comprehensive monitoring capabilities, automation features, and anomaly detection algorithms to provide users with real-time insights and control over key parameters such as water quality, lighting, feeding schedules, and fish behavior. Through functional testing and user acceptance evaluations, the study demonstrates the efficacy, usability, and high acceptance of the "Beyond the Tank" system among aquarium enthusiasts. The findings underscore the potential of IoT technology to revolutionize the fishkeeping experience, promote aquatic well-being, and drive innovation in aquarium management practices.

Keywords: Beyond d' Tank, African Cichlids, IOT, sensors, mobile app

1. Introduction

1.1. Background of the Study

With the rise of smart technologies, the field of aquarium management has witnessed significant advancements, offering enthusiasts innovative tools to create optimal environments for their aquatic companions. Among the myriad of fish species favored by hobbyists, African Cichlids have emerged as a popular choice due to their captivating colors, distinctive behaviors, and specific habitat requirements. However, catering to the needs of African Cichlid Fishkeeping presents unique challenges that necessitate tailored solutions.

1.2. African Cichlid Overview

African cichlids, as shown in Figure 1, are a diverse and colorful group of freshwater fish belonging to the family Cichlidae, primarily found in the rift lakes of Africa, including Lake Malawi, Lake Tanganyika, and Lake Victoria. African cichlids exhibit remarkable species diversity, with over 1,000 known species [1]. Renowned for their vibrant hues, unique behaviors, and adaptability to a range of aquatic environments, African cichlids have captivated the interest of aquarists and researchers alike.

Fig. 1: African Cichlid Freshwater Fish.

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African cichlids are popular aquarium fish due to their striking colors and intriguing behaviors, contributing significantly to the ornamental fish trade. Additionally, they serve as valuable model organisms for scientific research in areas such as speciation, behavior, and evolutionary ecology.

1.3. Evolution of Smart Aquarium Technology

In recent years, the field of aquatics has witnessed a remarkable evolution with the advent of smart aquarium technology. From simple glass tanks housing aquatic life to sophisticated ecosystems equipped with advanced monitoring, automation, and connectivity features, the journey of aquarium technology has been nothing short of transformative. This evolution has been driven by a confluence of factors, including advancements in sensor technology, miniaturization of electronics, and the growing demand for more efficient and user-friendly aquatic systems.

The concept of smart aquariums goes beyond mere containment of aquatic life; it encompasses a holistic approach to aquarium management, incorporating elements of connectivity, automation, and data-driven insights. Smart aquariums offer enthusiasts unprecedented control over water parameters, lighting, feeding schedules, and even remote monitoring capabilities, revolutionizing the way we interact with and care for our aquatic companions.

From hobbyists seeking to create optimal environments for their fish to researchers studying aquatic ecosystems, the appeal of smart aquarium technology spans a wide spectrum of applications. The integration of mobile applications, cloud-based data storage, and Internet of Things (IoT) connectivity has further expanded the possibilities, allowing users to monitor and manage their aquariums from anywhere in the world with just a few taps on their smartphones.

The Internet of Things (IoT) refers to a network wherein interconnected physical objects, referred to as "things," are furnished with sensors and connectivity to collect and share data via the Internet [2]. These objects range from devices and appliances to vehicles and living organisms, each endowed with distinct identifiers and capable of autonomous communication [3]. In the IoT paradigm, a complex network of connected objects collaborates to deliver useful insights, automate tasks, and introduce novel services [4].

Incorporating IoT into smart aquariums facilitates ongoing monitoring of critical parameters like water quality, temperature, lighting, and water flow through embedded sensors [5][6]. This instant data empowers enthusiasts to make accurate observations and modifications, guaranteeing optimal living conditions for aquatic inhabitants.

Smart aquarium systems function via wireless sensor networks, facilitating smooth communication and data transmission among sensors, actuators, and a central control system [7]. Presented through a mobile app or web-based interface, this central control system acts as an intuitive platform for enthusiasts to manage and regulate different aspects of the aquarium's functioning [8]. The mobile app allows users to adjust feeding schedules, manipulate lighting conditions, track water temperature, and receive prompt notifications regarding irregular or potentially hazardous situations [9].

Integrating IoT into smart aquariums introduces opportunities for automation, such as fish feed dispensers featuring servo motors and load cells [5]. These dispensers are programmable to dispense accurate food quantities at designated intervals, minimizing the chances of overfeeding or underfeeding aquatic inhabitants.

Smart aquariums powered by IoT provide more than mere convenience; they profoundly impact aquatic well-being. By continually monitoring water quality, pH levels, and turbidity, they ensure optimal conditions for fish health [6][9]. Additionally, remote control of lighting and simulation of natural day-night cycles positively influence the behavior and physiological state of aquatic creatures [10].

1.4. Objectives of the Study

The primary objective of this study is to design and develop "Beyond the Tank" exclusively crafted for African Cichlid Fishkeeping, integrating mobile technology and automation to enhance fish management and welfare. To achieve this overarching goal, the study sets forth the following specific objectives:

- Develop a dedicated mobile application, "Beyond the Tank," designed to streamline the management of African Cichlid Fish aquariums.
- Evaluate the effectiveness of "Beyond the Tank" in enhancing the management, monitoring, and care of African Cichlid Fish.
- Investigate the impact of automation features, such as remote monitoring and feeding schedules, on the health and well-being of African Cichlid Fish.
- Provide insights into how the integration of modern technology can revolutionize the fishkeeping experience and promote the welfare of African Cichlid Fish in captivity.

1.5. Significance of the Study

This study holds significant implications for both African Cichlid enthusiasts and the broader community of aquarium hobbyists. By leveraging cutting-edge technology, "Beyond the Tank" aims to redefine the standards of fishkeeping, offering a comprehensive solution that enhances the user experience while prioritizing the health and happiness of aquatic inhabitants. Moreover, the insights gained from this research endeavor have the potential to drive innovation in the field of aquatic habitat management, paving the way for future advancements in aquarium technology.

2. Literature Review

2.1. African Cichlids

Cichlids stand out as one of the most varied fish groups, found across North America, Central America, South America, and Africa. Figure 2 shows different variations of just some of the African Cichlids.

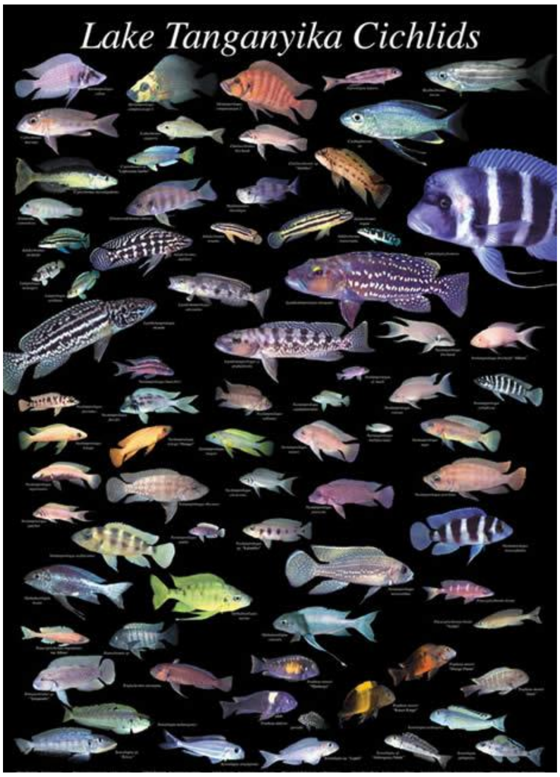

Fig. 2: Lake Tanganyika Cichlids.

Renowned for their wide range of sizes, shapes, and colors, these fish are highly valued by enthusiasts. Notably, African lake cichlids represent one of the most evolutionarily diverse groups globally, with numerous species evolving within confined ecological niches [11]. African cichlids are notably active, rendering them a beloved choice among aquarium enthusiasts for their lively displays. While they demand particular attention, their resilience makes many varieties suitable for novice aquarium owners. This species offers a plethora of vibrant colors and intricate patterns, though it may take up to a year for them to fully develop their distinctive hues. The quality of care they receive significantly influences their coloring [12].

2.2. African Cichlids Care

Table 1 offers a detailed overview of key care information for African Cichlids, including their common names, scientific classification, origins, size, behavior, preferred temperature, water parameters, minimum tank size, and suitable tank mates. This resource provides valuable guidance for enthusiasts aiming to create ideal conditions for the health and happiness of these captivating aquatic creatures.

Table 1: Discus Fish Care Summary [13]

Aspect	Information
Common names:	African Cichlids
Scientific Name:	Pseudotropheus sp
Origins:	Lake Malawi, Lake Tanganyika, and Lake Victoria
Size	Approx. 2 to 12 inches
Behavior/ Temperament:	Aggressive
Temperature:	75–85°F (24–29°C)
Water Chemistry	pH Level - 7.8–8.6
Hardness	12–30 dGH
Current	Low to Moderate
Minimum tank size:	100 gallons
Care Level	Moderate
Water type	Moderately hard, tropical freshwater
Feeding Frequencies	They should be fed twice daily.
Best Food Recommendations	Small fish meat, tubifex worms, insects, cichlid pellets, frozen food, wafers, or brine shrimp, along with some fruits and vegetables.
Ease of Care:	Moderate to Hard

2.3. Integration of Wireless Sensor Networks and IoT

Al-Sheikh and colleagues (2019) devised an IoT-driven smart aquarium monitoring system that integrates wireless sensor networks to track real-time water quality parameters, temperature, and humidity. This system incorporates a centralized server and a mobile application for comprehensive monitoring and control [5]. Similarly, Xu et al. (2019) introduced a smart aquarium monitoring system utilizing Zigbee, a wireless sensor network, for instantaneous monitoring of water quality, temperature, and lighting conditions. Their system provides data and control functionalities through a dedicated mobile application [7]. Both studies underscore the use of wireless sensor networks and IoT for continuous surveillance and remote monitoring in smart aquarium setups.

2.4. Water Quality Monitoring and Analysis

The paper "Development of a Smart Aquarium System for Water Quality Monitoring" by Selvarajoo and Lee (2019) focuses on a microcontroller-based system with a web interface for comprehensive pH, temperature, and dissolved oxygen content monitoring [6]. With this configuration, water quality can be actively controlled and monitored in real-time. Similar to this, Tanveer and Parvin's research from 2020, "Smart Aquarium Management System Using IoT and Mobile Application," describes a system for dynamic real-time analysis of temperature, lighting, and water quality that combines IoT with a mobile app [8]. The user-friendly mobile application provides convenient remote monitoring and control.

2.5. Image Processing and Fish Behavior Analysis

In their paper "Smart Aquarium Monitoring and Control System Using IoT and Image Processing," Bansal and Rawat (2020) presented a revolutionary system that combines IoT technology with image processing to monitor temperature, aquatic behavior, and water quality in real-time. Via a dedicated mobile application, the system provides control and monitoring features [9].

2.6. Machine Learning for Anomaly Detection and Fish Health Monitoring

In their 2020 study, Wang et al. examined the "Smart Aquarium Management System Based on IoT and Machine Learning," presenting a system that combines IoT and machine learning to identify anomalies in temperature, lighting, and water quality [15]. The application of machine learning algorithms improves aquarium management decision-making procedures. In a similar vein, Patel and Kumar's research from 2021, "IoT-Based Smart Aquarium for Fish Health Monitoring and Analysis," concentrated on an Internet of Things system intended for fish health monitoring. This system uses sensors to measure temperature, water factors, and fish activity. Machine learning techniques do real-time analysis of the data, and alarms are sent via a mobile application [14].

2.7. Cloud Computing and Remote Access

In their study "Utilizing IoT and Cloud Computing for Smart Aquarium Management," Zhang et al. (2021) introduced a system that makes use of cloud computing and IoT to remotely monitor temperature, lighting, and water quality [16]. Cloud computing plays a key part in this system, providing the foundation for data analysis, storage, and overall aquarium system management.

2.8. User Acceptance Test (UAT) and Evaluation

Rey and Rolluqui (2021) highlighted how important system usability is to IoT-based platforms' efficacy. Their emphasis on usability draws attention to the significance of user-friendly interfaces that can accommodate users with different degrees of technical proficiency, which is an essential factor in the adoption and use of Internet of Things applications [17].

3. Methodology

A thorough description of the steps, procedures, and feedback loops involved in creating and assessing the Beyond d' Tank IoT system can be found in Figure 3. The steps and components needed to create an Internet of Things (IoT) enabled aquarium setup are outlined in this organized framework. Prerequisite knowledge includes knowledge of electrical and electronics principles, programming experience, and software specifications such as development environment integration and C++ programming language usage. Important parts, including the Node MCU microcontroller, several sensors, pumps, and filtration media, are described in detail in hardware specifications. Initialization, planning, requirements formulation, design, implementation, deployment, testing and verification, and evaluation are all steps in the process. The Beyond d' Tank Internet of Things system and accompanying mobile app for remote monitoring and control are examples of output. Functional testing and system evaluation are included in feedback loops to make sure the system satisfies user needs and specified requirements.

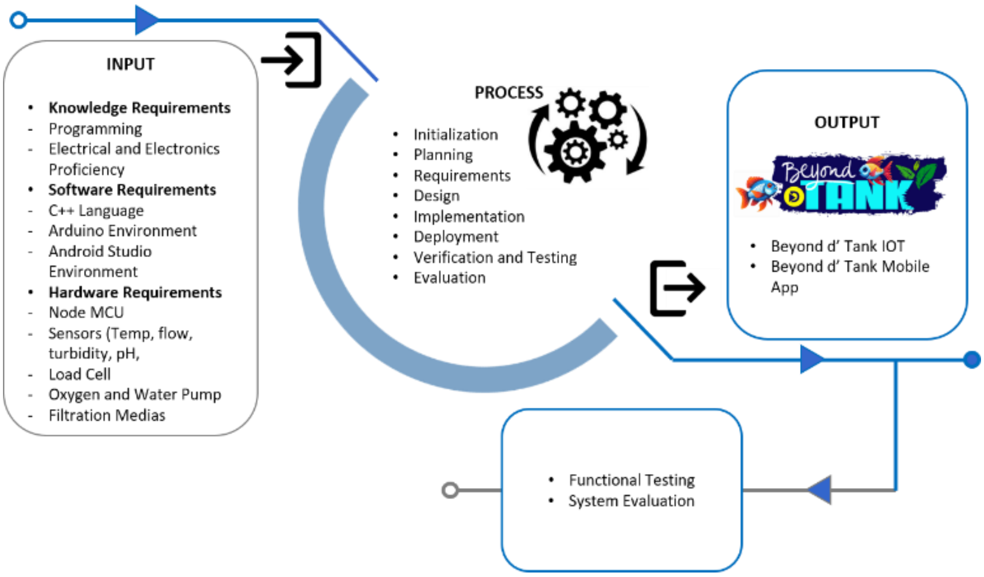

Fig. 3: Research Paradigm.

3.1. Block Diagram

The smart and innovative aquarium experience created by the Beyond d' Tank technology completely changes how aquarium enthusiasts engage with their aquatic surroundings. With the help of an advanced range of sensors and actuators, this system allows for remote monitoring and control over the Internet, improving functionality and offering a smooth user experience. The essential elements and characteristics shown in Figure 4 clarify the subtleties of this sophisticated system.

First off, the Fish Feed Dispenser automates fish feeding by letting customers track the amount of food delivered and remotely monitor and regulate feeding schedules using a special mobile application. Second, the addition of a Temperature Sensor allows for constant observation of the aquarium's water temperature, guaranteeing ideal circumstances for fish health. Thirdly, users can imitate natural lighting patterns and create the perfect environment for the fish by using the Manual Control feature of the Lighting System, which gives adjustable lighting options. In order to guarantee adequate circulation, the Flow Sensor also measures water flow rates. It then automatically modifies the flow rate according to the water level to avoid stagnation. Lastly, the addition of a turbidity sensor allows for ongoing water quality monitoring. It provides customers with real-time information to help them maintain the best possible water conditions for fish health.

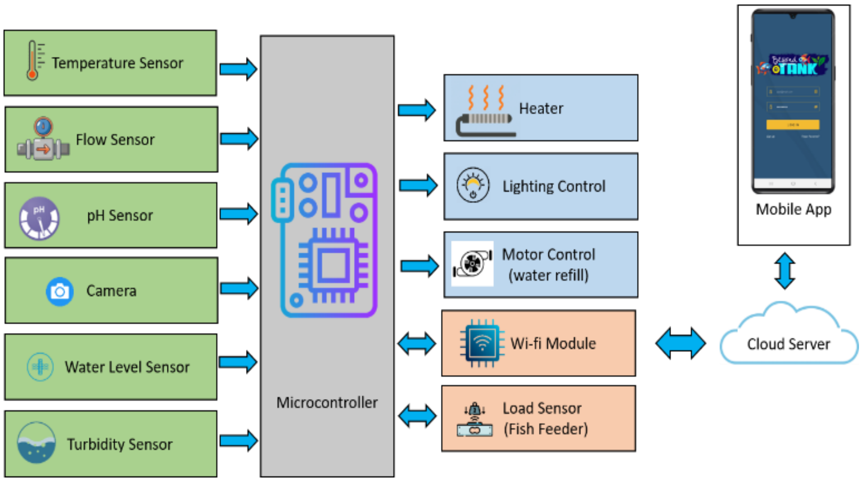

Fig. 4: Block Diagram.

3.2. Hardware Components

The Beyond d' Tank system's hardware components are made up of an extensive range of technologies designed to maximize aquarium management and guarantee a healthy aquatic environment. First off, the Node MCU includes the Lua programming language and the ESP8266 Wi-Fi System-on-a-Chip (SoC), offering a strong foundation for the smooth integration of IoT features. The Temperature Sensor (DS18B20) provides precise real-time temperature data, improving the accuracy of monitoring. The fish receive the best nutrition possible thanks to the accurate food quantity measurement made possible by the Loadcell and HX711. Relays are essential components for turning circuits on and off and are essential in managing the flow of electrical power. Precise monitoring and control are made possible by the Flow Sensor, which measures the water and airflow rates. A healthy aquatic environment is promoted by the Oxygen Pump, which guarantees appropriate oxygen levels for fish health. While the pH sensor measures the acidity or alkalinity of water to offer information about its chemistry, the turbidity sensor measures the cloudiness caused by suspended particles. In order to maintain ideal flow, oxygen levels, and filtration, the water pump moves and circulates water. Last but not least, filtering media helps with important mechanical, chemical, and biological filtration processes by eliminating contaminants. By combining these hardware elements, Beyond d' Tank is established as a state-of-the-art aquarium system that ensures a complete and healthy habitat for aquatic life.

3.3. Software Components – Mobile App

With its ability to monitor and control the aquarium remotely, the smartphone app is an essential tool for aquarium management. It communicates with a cloud server to give users instant access to important information like pH and temperature readings. Users can remotely modify settings and receive alerts for any changes. Internet connection is guaranteed from any location, thanks to cloud connectivity. The software makes managing aquariums easier and gives users the control to keep their aquatic ecosystem in ideal conditions.

3.4. System Architecture

The design of the Beyond d' Tank system is shown in Figure 5, which highlights the incorporation of IP-enabled devices, sensors, and IoT applications inside the cage. These sensors keep an eye on things like humidity and temperature. Sensor data is sent to Internet of Things (IoT) devices, which then transfer it to the cloud to be stored. Efficient monitoring and control are ensured by the web-based interface and mobile application that allow users to view and manage cage parameters.

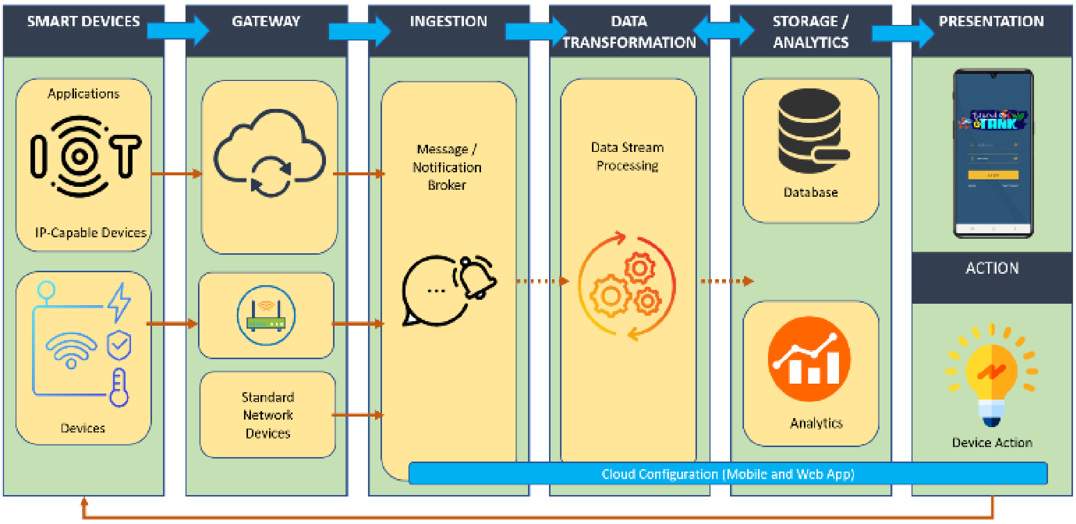

Fig. 5: System Architecture.

4. Results and Discussion

This section will explore Beyond the Tank: Next-Generation Aquaria for the African Cichlid Fishkeeping community in mind. This system provides a comprehensive and user-friendly solution that makes it easier to operate Discus-dedicated aquariums thoroughly and efficiently through seamless connection with web and mobile applications.

4.1. Beyond d' Tank Circuit

The electronic circuits and parts that make up the Beyond d' Tank system are shown graphically in Figure 6. These include microcontrollers, sensors, actuators, power supply components, and other vital electronic parts required for the system to function and operate well.

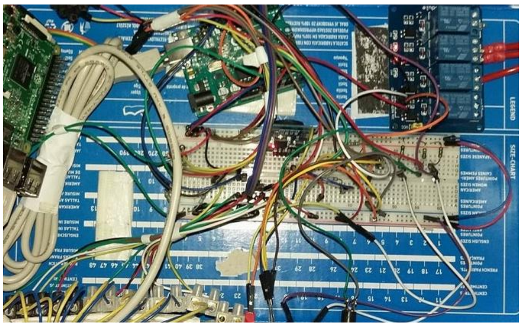

Fig. 6: Beyond d' Tank Circuit.

4.2. Beyond d' Tank Mobile App

The Beyond d' Tank mobile application, as illustrated in Figure 7, provides several essential functions aimed at enhancing user experience and streamlining aquarium maintenance:

- Dashboard and Monitoring: Displaying crucial aquarium data such as water temperature, pH levels, and alerts on a centralized dashboard, users can effortlessly monitor current conditions.
- Remote Control: Enabling users to adjust lighting, regulate water flow, configure filtration systems, and schedule feeding times remotely through the application.
- Water Quality Analysis: Using data from aquarium sensors, the app visually analyzes water quality, offering insights and recommendations for necessary adjustments.
- Feeding Management: Allowing users to schedule and regulate automatic feeding, specifying feeding times, portion sizes, and types of food.

- Maintenance Reminders: Sending reminders for tasks such as water changes and filter cleanings, assisting users in maintaining proactive aquarium care.
- Historical Data and Analytics: Providing users with access to historical water parameters and feeding schedule data through graphs, facilitating trend tracking, and informed decision-making.
- Alerts and Notifications: Delivering timely alerts for critical events such as abnormal water conditions or equipment malfunctions, empowering users to respond promptly.

Fig. 7: Beyond d' Tank Circuit.

These features contribute to user-friendly aquarium management, ensuring optimal conditions for aquatic inhabitants.

4.3. Beyond d' Tank Testing Preparation

System testing came next, following the conclusion of unit and integration testing. Ensuring the fully integrated system operated as intended and complied with all requirements was the major goal. During this testing phase, several aspects were verified:

- Extensive Testing Scenario: By analyzing how various components interacted, external modules assisted in conducting an extensive test of the entire system. From one end of the system to the other, everything was covered.
- Input-Output Validation: Every input was thoroughly examined to make sure the right output was generated. A few tests revealed problems or inaccuracies in the output, which the researcher corrected. They examined the issues and made the required software modifications after examining the unsuccessful tests.

4.4. Functional Testing Results

After several testing iterations, the functionality testing results for the Internet of Things (IoT)-based aquarium system, displayed in Table 2, demonstrate that all requirements were satisfied. Every prerequisite was thoroughly examined and found to be compliant. The system has an easy-to-use interface that accommodates users with varying technical skills and seamlessly combines IoT technology with a mobile app for monitoring and controlling multiple parameters. The system displayed real-time water quality analysis, continuous aquarium environment monitoring, and image processing-based fish behavior observation.

Table 2: 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

In addition, irregularities in temperature, lighting, and water quality were successfully identified by machine learning algorithms. Well-integrated was a system for keeping an eye on fish health that made use of sensors for temperature, water quality, and fish activity. For distant data storage, analysis, and general system management, cloud computing was essential. The system's acceptability and usability were guaranteed via user acceptance testing.

Even though testing was difficult, the system went through several revisions to fix problems and enhance usefulness. These positive results demonstrate the system's dependability and efficiency, satisfying the demands of cichlid lovers and promoting intelligent aquarium management solutions.

4.5. Anomaly Detection in Water Quality

The technology uses an advanced machine learning technique called Isolation Forest to identify anomalies in water quality metrics. This algorithm is quite good at identifying odd patterns in data, such as outliers in water quality measures, since it is skilled at identifying anomalies by isolating them in a binary tree structure [18]. In order to successfully identify anomalies from the usual data, Isolation Forest isolates data points by randomly choosing features. The strong anomaly detection provided by this approach is well-suited to the dynamic nature of aquarium systems. The IoT-based aquarium system's capacity to quickly and precisely identify variations in variables like pH levels, temperature, and dissolved oxygen content is enhanced by this algorithm, which also helps the system maintain the ideal conditions for cichlid fish.

4.6. Beyond d'Tank Summative User Evaluation Results

Table 3 presents the summary results of user evaluations for the "Beyond d' Tank" system, utilizing the Post-Study System Usability Questionnaire (PSSUQ). The table showcases weighted mean scores, standard deviations, and verbal interpretations for distinct categories of user experience.

In terms of System Usefulness, users rated the system highly acceptable, with a weighted mean score of 1.55 and a standard deviation of 0.59. Similarly, the Information Quality received a high acceptability rating, with a weighted mean score of 1.40 and a standard deviation of 0.79. Interface Quality also scored highly acceptable, with a weighted mean score of 1.50 and a standard deviation of 0.59. Overall satisfaction with the system was notably high, as indicated by a weighted mean score of 1.58 and a standard deviation of 0.52.

Table 3: Beyond d' Tank User Evaluation Summary Results

PSSUQ Overall Category	Weighted Mean	Standard Deviation	Verbal Interpretation
System Usefulness	1.55	0.59	Highly Acceptable
Information Quality	1.40	0.79	Highly Acceptable
Interface Quality	1.50	0.59	Highly Acceptable
Overall, I am satisfied with this system.	1.58	0.52	Highly Acceptable
PSSUQ Overall Mean	1.51	0.62	Highly Acceptable

The PSSUQ Overall Mean, combining scores across all categories, further reinforces the positive reception of the "Beyond d' Tank" system, with a weighted mean score of 1.51 and a standard deviation of 0.62. These results collectively suggest that users found the system to be highly satisfactory and acceptable across various dimensions of usability and performance.

5. Conclusion

For enthusiasts of African cichlids, the Beyond d' Tank system represents a major development as it combines cutting-edge IoT technology with sophisticated monitoring functions. This paper highlights the significance of Beyond d'Tank in the field of smart aquarium management systems by delving deeply into its creation, operation, and practical applications. This technology not only meets the special needs of Cichlid Fish but also improves the whole experience of keeping aquariums by fusing technological innovation with aquatic science.

5.1. Key Findings and Contributions

With its sophisticated and all-inclusive aquarium management system that provides automatic duties and real-time monitoring, the Beyond d' Tank distinguishes out. With the help of sensors, cloud connectivity, and an intuitive mobile app interface, aquarists may regulate vital factors that guarantee the health of their Cichlid fish. The Isolation Forest and other machine learning techniques enable anomaly identification, which contributes to the preservation of a stable and wholesome aquatic ecosystem. Users' pleasure with the system's utility, information quality, interface quality, and overall experience validate its effectiveness, and the PSSUQ user evaluation shows good acceptance and usability.

5.2. Future Implications and Recommendations

Subsequent research endeavors may examine the customization of intelligent aquarium systems to enhance the welfare of diverse fish species. Improvements like more sophisticated lighting schemes and improved feeding mechanisms may make aquarium maintenance simpler. Creating a user base for Beyond d' Tank could facilitate knowledge sharing and system improvement over time.

6. References

[1] Salzburger, W.; Mack, T.; Verheyen, E.; Meyer, A. (2005). "Out of Tanganyika: Genesis, explosive speciation, key-innovations and phylogeography of the haplochromine cichlid fishes." BMC Evolutionary Biology. 5 (17): 17. doi:10.1186/1471-2148-5-17. PMC 554777. PMID 15723698.

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

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

[4] 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.

[5] 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.

[6] 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

[7] 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.

[8] 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.

[9] 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.

[10] Xu, L., Zeng, L., Yang, Z., & Luo, L. (2019). Smart Aquarium Monitoring System Based on Wireless Sensor Network.

[11] Stephen M. Miller, Mark A. Mitchell, CHAPTER 4 - ORNAMENTAL FISH, Editor(s): Mark A. Mitchell, Thomas N. Tully, Manual of Exotic Pet Practice, W.B. Saunders, 2009, Pages 39-72, ISBN 9781416001195, https://doi.org/10.1016/B978-141600119-5.50007-X.

[12] Allison Yang. (2022). "African Cichlid Care Guide: Tank Setup, Types & Tank Mates." Aquarium Source. Last edited: February 9, 2022. Retrieevd from: https://www.aquariumsource.com/african-cichlids/.

[13] Mari. (2023). "African Cichlid Fish: Everything You Need To Know". Last Updated: April 20, 2023. Aquariadise. Retrieved from: https://www.aquariadise.com/african-cichlid-fish/.

[14] 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.

[15] 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.

[16] 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.

[17] 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.

[18] 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.