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Aquatrack: A System Architecture for Sustainable Bangus Farming

Erin Joy C. Doria[1], Ronmark P. Catabay[2], Renz Gabriel R. Ragudos[3], Jenecess R. Romero[4], Mark Leslie D. Melendez[5]

Bachelor of Science in Information Technology, Pangasinan State University, Philippines

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ABSTRACT

In the modern aquaculture industry, maintaining water conditions is essential for the sustainable production of Bangus. Despite advancements in fisheries, many local operators still rely on traditional manual monitoring methods that are time-consuming, prone to human error, and insufficient for addressing risks such as fish mortality, poor water quality, and bird predation. To address these challenges, AquaTrack was developed—an integrated web-app smart buoy system designed to automate monitoring and protect fish stocks. The study follows a developmental research approach using the Rapid Application Development model, allowing for iterative prototyping and continuous stakeholder feedback. The system is built on a three-tier architecture, utilizing an ESP32 microcontroller and various sensors to measure water temperature, pH, and dissolved oxygen in real-time. Beyond monitoring, the system integrates automated feeding alerts and a sound-based bird deterrent to enhance farm management. To ensure technical reliability, the system's acceptance level was evaluated through survey questionnaires based on ISO-25010 Software Quality Standards, involving fishpond owners, farmers, and IT experts. Results demonstrate that AquaTrack effectively provides accurate, real-time data storage and retrieval, significantly reducing operational risks. By consolidating monitoring and management into one accessible platform, the system enhances academic and professional workflows in aquaculture, contributing to a more technology-responsive and sustainable farming environment.

Keywords: sustainable aquaculture, culture fisheries, bangus farming, real-time monitoring, smart buoy

INTRODUCTION

In an era of rapid technological advancement, the integration of innovation into the agricultural sector plays a crucial role in ensuring food security and economic stability. Within the fisheries industry, aquaculture has emerged as a vital practice, requiring the cultivation of aquatic organisms within managed environments where water quality and growth cycles are strictly regulated for peak production (Tsai et al., 2022). Having convenient, real-time access to high-quality environmental data is essential to ensure a sustainable and technology-responsive farming environment.

Recent studies emphasize the pivotal role of the Internet of Things (IoT) in supporting aquaculture by addressing the limitations of manual monitoring (Chen et al., 2022; San Antonio et al., 2023). While conventional instruments such as handheld pH and dissolved oxygen (DO) meters are widely used, they often lack the ability to perform automated, continuous measurements or generate real-time reports (Chen et al., 2022). To mitigate this, various researchers have designed frameworks leveraging open-source hardware and sensors to implement real-time aquatic monitoring (Islam et al., 2022; Subowo & Pradita, 2024). These IoT frameworks serve as intelligent prediction and continuous monitoring networks that merge machine learning capabilities with sensor data to optimize water quality parameters (Baena-Navarro et al., 2025). Furthermore, the application of automated feeding control alongside water quality tracking has been shown to improve fish growth metrics while stabilizing the aquatic habitat (Aljehani et al., 2023).

Despite these global advancements in sensor technology and smart control systems, they remain underutilized in local aquaculture settings, leaving farmers vulnerable to unfavorable environmental changes. In the Philippines, aquaculture plays a significant role in food production and livelihood, yet many fish farming practices still rely on traditional methods that are time-consuming and prone to human error (Bachtiar et al., 2022). These manual processes lead to inaccurate data collection, making it difficult for farmers to respond promptly to ecological risks. The development of intelligent water quality management systems specifically tailored for aquaculture aims to overcome these exact limitations by providing automated feedback loops (Olanubi et al., 2024). Additionally, real-time remote monitoring systems have demonstrated measurable success in safeguarding water quality integrity over long distances ("Real-time remote monitoring system for aquaculture water quality," 2020).

At the local level in Sabangan, Alaminos City, *bangus* (milkfish) farmers continue to experience significant difficulties in managing their ponds. A critical gap observed by the proponents is that farmers often face challenges in monitoring multiple parameters—such as temperature, pH, and dissolved oxygen—simultaneously. Existing processes are largely manual, leading to delayed decision-making and increased financial losses due to fish kills and bird predation. Because farmers cannot be present at the ponds 24/7, there is a clear need for an automated system that can provide remote assistance and consistent real-time data monitoring.

Implementing accessible, low-cost microcontrollers, such as Arduino units paired with mobile applications like Blynk, has proven highly effective for tracking critical metrics like pH and temperature in localized shrimp and fish ponds (Hantoro, 2023; Pauzi et al., 2017). Similar mobile-integrated IoT systems featuring waterproof temperature probes have successfully optimized real-time fishpond oversight in regional settings (Natividad et al., 2023). Implementing these frameworks in underfunded areas is critical, as recent deployments of IoT-based water quality monitoring systems in Philippine off-grid communities have successfully proven that remote, real-time health monitoring is achievable even in resource-constrained environments (Abrajano et al., 2024; Sarwar & Iqbal, 2022). Consequently, this study develops a specialized, automated monitoring solution to protect local *bangus* production and secure the livelihoods of the Sabangan farming community.

To address these challenges, the proponents proposed AquaTrack, a web-app smart buoy system designed to centralize and automate water quality management. The study aims to (1) identify the existing process in real time monitoring and water quality parameters, (2) identify the difficulties in real time monitoring and water quality parameters, (3) identify key features to be integrated into the system's development; and (4) to test the usability through ISO-25010 Software Quality Standards.

METHODOLOGY

The proponents employed a design and development research approach to develop the AquaTrack Smart Buoy System for sustainable bangus farming. This approach was used to identify and analyze existing problems in traditional fishpond monitoring, such as human error, labor-intensive processes, and delays in water quality assessment.The developmental aspect of the study focused on the systematic design, creation, and refinement of the proposed system to transform manual monitoring processes into an automated, accurate, and user-friendly web-app platform. This ensured that all system features were aligned with the requirements of fishpond operators and stakeholders, particularly in monitoring water quality parameters such as dissolved oxygen, temperature, salinity, and pH levels. In developing the proposed system, the proponents adopted the Rapid Application Development (RAD) methodology, as shown in Fig. 1.

This model was chosen due to its iterative nature, allowing continuous user feedback and rapid improvements throughout the development process. The RAD approach facilitated the creation of functional prototypes that were refined through repeated evaluation and testing, ensuring system accuracy, usability, and efficiency.

The development process involved key phases including requirements planning, system design, prototype development, testing, and implementation. Through this cycle, the AquaTrack Smart Buoy System was deployed in selected fishpond areas, where sensors continuously collected water quality data and transmitted it wirelessly to a web-app monitoring platform accessible via computers and mobile devices.

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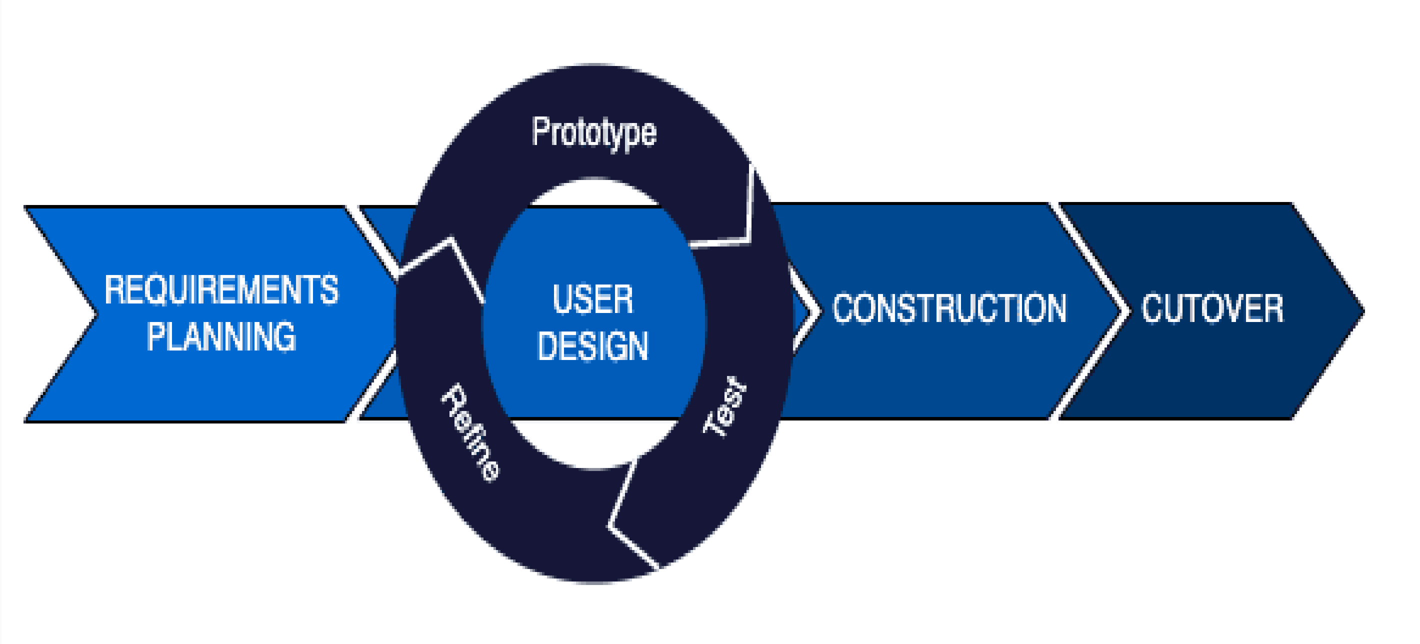

Rapid Application Development Model

Source:https://www.agilelonestar.com/knowledge-base/rapid-application-development

The development of AquaTrack follows a Rapid Application Development (RAD) approach, prioritizing iterative prototyping and continuous stakeholder feedback. This methodology ensures that the final system is highly functional, user-centric, and delivered within a condensed timeframe.

Requirements Planning this phase focuses on understanding broad business challenges rather than producing exhaustive specifications. It establishes the foundation by identifying essential requirements the solution must meet. To maximize effectiveness, developers collaborate with all stakeholders in a continuous engagement process. This ensures everyone is aligned, preventing costly miscommunications from spilling into subsequent stages. This stage is often condensed, sometimes completed in as little as a single meeting.

User Design is a collaborative phase where fishpond leaseholders and stakeholders interact directly with developers to refine system requirements. Prototypes of AquaTrack are created and iteratively improved based on user feedback. These mockups allow stakeholders to assess functionality before full-scale development begins. Once a mockup satisfies the requirements, a working prototype is developed, allowing for design adjustments before the heavy coding phase, which minimizes the need for major changes later.

Construction Once the design is refined, rapid construction begins. This includes the coding and testing of functional modules such as water quality monitoring, automated feeding alerts, real-time fish mortality detection, and sound-based bird deterrents. Following RAD principles, these modules are built in parallel using reusable code and component libraries to shorten development time. Continuous Integration and Continuous Deployment (CI/CD) pipelines are utilized to ensure seamless updates and minimize integration issues during iterative testing cycles.

The Cutover phase involves final system testing, user training, and transitioning the application to the live environment. This is the final stage of the SDLC where all documentation is verified for quality and User Acceptance Testing (UAT) is conducted. During UAT, end-users validate the final product to ensure it meets their operational needs. This phase also includes a final sweep for debugging and fixing any remaining broken code.

After the successful cutover, the application enters a phase of ongoing refinement. The RAD model assumes that no system is ever "fully complete" upon its initial release; therefore, post-launch support is critical.

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Developers continue to provide support and evolve the system based on real-world user feedback, ensuring AquaTrack remains effective as the needs of the leaseholders grow.

The researchers conducted convenient sampling among fishpond stakeholders and IT experts in order to gain both practical and technical perspectives for system development. A total of 30 respondents participated in the study, consisting of 5 fishpond owners and leaseholders, 20 bangus farmers and 5 IT experts. Table 1 presents a list of those who took apart in the research investigation.

Table 1. Respondent of the Study

Respondents	Number of Respondents
Fishpond Owners and Leaseholders	5
Bangus Farmers	20
IT Experts	5
Total Respondents	30

The researchers assessed system performance and improvement using a 5-point Likert Scale, where Excellent received the highest rating of 3.26 - 4.00 while Poor had the lowest value of 1.00 – 1.75. system was considered unacceptable. To ensure clarity and precision in data interpretation, the researchers established standardized statistical thresholds to categorize the findings. These ranges allow for a consistent evaluation of the system's performance metrics and stakeholder feedback. The scale and its statistical limits are presented in Table II.

Table 2. Scale of Measurement

Scale	Statistical Limits	Rating	Descriptive Interpretation
1	1.00 – 1.80	Not Evident	The system is hard to use and needs major improvements.
2	1.81– 2.60	Less Evident	The system works but has several areas for improvement.
3	2.61 – 3.40	Evident	The system is easy to use with only a few minor issues.
4	3.41 – 4.20	More Evident	The system is smooth and user-friendly with minimal issues.
5	4.21 – 5.00	High Evident	The system is intuitive, efficient, and seamless to use.

RESULTS AND DISCUSSIONS

The development of the AquaTrack system successfully leveraged digital transformation in aquaculture by automating water quality monitoring through a robust three-tier architecture. The Application Tier, controlled by an ESP32 microcontroller, effectively processed real-time data from integrated sensors measuring pH, temperature, salinity, and dissolved oxygen (DO). The Data Tier managed the automated logging of these parameters into a centralized database for historical tracking, while the Presentation Tier delivered this information via a web-app interface and SMS alerts to stakeholders. This architectural framework successfully replaced the error-prone manual observation methods identified in the existing process.

The technical performance of the AquaTrack architecture was validated through an evaluation based on ISO-25010 Software Quality Standards, yielding an overall weighted mean of 4.48 (More Evident). Specifically, the system achieved high scores in Functionality (4.82) and Portability (4.58), proving that the hardware sensors provide accurate readings and the buoy is easy to deploy in the actual fishpond environments of Sabangan, Alaminos City. Furthermore, the high score in Maintainability (4.60) suggests that the system is easy for local operators to manage long-term, while the Portability results indicate high adaptability to different pond conditions. These findings demonstrate that the system is a viable, sustainable alternative to manual monitoring, significantly reducing the risk of fish kills through real-time environmental alerts and automated management features.

Proposed System Architecture

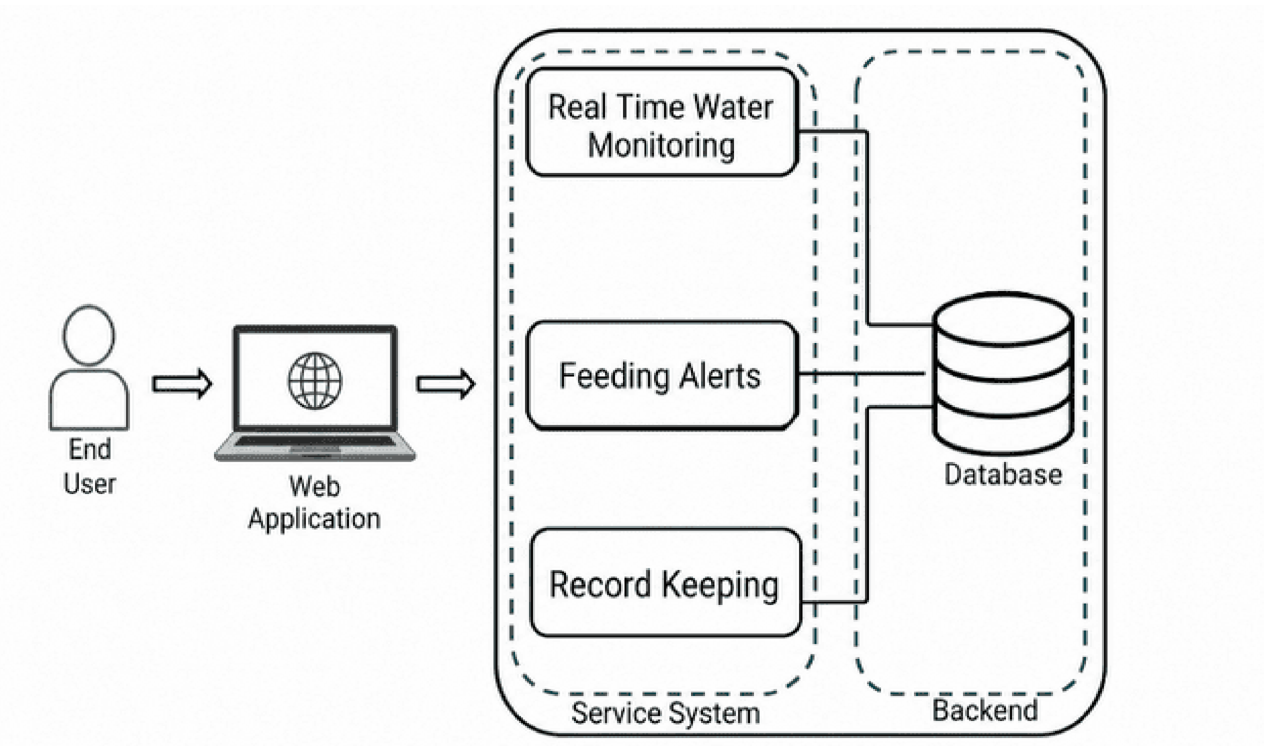

Figure 3. AquaTrack A Web-App Smart Buoy System for Sustainable Bangus Farming Three-Tier Architecture

The AquaTrack: Web-App Smart Buoy System the presentation tier, the user-facing interface, addresses the needs of fishpond managers and operators. Users interact with the system through a web-app dashboard, where they can view real-time water quality readings, feeding the schedules and access historical records. This tier also encapsulates functionalities such as alert notifications, and data visualization, serving as the primary gateway for interaction with the system.

The Presentation Tier is the user interface (UI) layer where the system and the user interact. It is responsible for displaying information and receiving inputs through web technologies such as HTML, CSS, and JavaScript. In the AquaTrack system, this tier allows fishpond operators to access real-time water quality data, alerts, and records through a web-app dashboard. It ensures an ideal user experience by presenting clear visualizations of parameters such as temperature, pH level, salinity, and dissolved oxygen, while also enabling interaction with system features like monitoring controls and notification settings.

The Application Tier serves as the core of the system, containing the business logic and system services of AquaTrack. It is developed using Node.js, which handles server-side processing and enables real-time communication between the frontend, sensors, and database. This tier processes all data collected from the smart buoy sensors based on defined monitoring rules and system requirements. It manages real-time water quality monitoring, feeding alerts, and bird deterrent notifications to support efficient fishpond management. The system continuously analyzes incoming sensor data and triggers alerts when abnormal water conditions are detected. It also processes stored data for trend analysis and decision-making support, allowing farmers to respond quickly to environmental changes and risks such as fish kills.

The Data Tier, also known as the database layer, serves as the foundation of the three-tier architecture where all collected information is stored and managed. In the AquaTrack system, this tier is responsible for securely storing sensor readings, user records, monitoring history, alerts, and system logs. It ensures data integrity, security, and availability for both real-time access and historical analysis. The stored data is retrieved by the Node.js-based application tier to generate reports and support continuous monitoring of fishpond conditions, ensuring accurate and reliable information for decision-making.

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Problems and Proposed Solutions

The traditional fishpond monitoring process in Sabangan, Alaminos City, presents critical operational vulnerabilities because stakeholders rely entirely on visual inspection and manual record-keeping. Site observations and interviews revealed that this traditional approach leads to severe data inaccuracy from pen-and-paper logging, delayed responses to sudden environmental shifts that directly cause fish kill incidents, and overall operational inefficiency due to the requirement of a constant physical presence at the ponds. To address these interconnected challenges, the researchers developed AquaTrack, an integrated web-app smart buoy system built on a robust three-tier architecture designed to automate the entire monitoring lifecycle.

This technical framework eliminates human error and optimizes data flow by separating responsibilities into three distinct layers. The Presentation Tier serves as the primary user interface, rendering real-time environmental visualizations, interactive feeding schedules, system logs, and automated SMS alerts directly to fishpond managers. Beneath this, the Application Tier handles the core business and operational logic. It utilizes an ESP32 microcontroller embedded within the smart buoy for localized, real-time sensor data acquisition of pH, temperature, salinity, and dissolved oxygen (DO), while managing automated hardware actions such as the sound-based bird deterrent system. This hardware edge layer communicates directly with a server-side Node.js application that governs backend data routing, alert threshold evaluations, automated feeding schedule triggers, real-time fish mortality detection algorithms, and frontend interface synchronization. Finally, the Data Tier forms the foundation of the architecture, automating historical data archiving by securely logging all incoming sensor parameters, user records, and triggered notifications into a centralized database, thereby replacing error-prone manual records with an immutable, accessible data repository.

To empirically validate the effectiveness of this proposed framework over the existing manual methods, the technical performance of the AquaTrack architecture was evaluated using the industry-standard ISO/IEC 25010 Software Quality Model. This standard systematically measures software and hardware integration across vital criteria to prove the system's readiness for real-world deployment. The evaluation yielded an overall weighted mean of 4.48, which translates qualitatively to a "More Evident" rating across all measured quality characteristics. Exceptional performance was noted in Functional Suitability (4.82) and Portability (4.58), demonstrating that the integrated hardware sensors provide highly precise readings and that the physical buoy is optimized for easy deployment within the specific, fluctuating aquatic environments of Sabangan. Furthermore, a high rating in Maintainability (4.60) suggests that local operators can independently manage, update, and troubleshoot the system over long-term operations. These empirical findings confirm that the proposed technical framework offers a viable, sustainable, and highly reliable alternative to manual monitoring, significantly reducing local aquaculture risks through real-time environmental insights, as detailed in the evaluation summary below.

Table 3. System Evaluation According to Overall Weighted Mean

Overall Weighted Mean	Mean	Description
Functionality	4.82	More Evident
Efficiency	4.43	More Evident
Compatibility	4.36	More Evident
Usability	4.33	More Evident
Reliability	4.34	More Evident
Security	4.4	More Evident
Maintainability	4.60	More Evident
Portability	4.58	More Evident
Overall Weighted Mean	4.48	More Evident

CONCLUSION

Along with the growing demand for sustainable and technology-driven aquaculture practices, continuous innovation in fishpond management has become essential to improve productivity, reduce losses, and ensure long-term sustainability. The design and development of the AquaTrack: Web-App Smart Buoy Monitoring System address critical challenges faced by bangus farmers, particularly in monitoring water quality, feeding schedules, and overall pond conditions. By replacing manual monitoring and paper-based record-keeping with an automated, web-app system, AquaTrack simplifies operational processes while improving the accuracy and reliability of collected data.

This system enables real-time monitoring and centralized data storage, allowing fishpond managers to make informed decisions promptly and efficiently. AquaTrack supports sustainable aquaculture practices by promoting timely interventions, better resource management, and improved fish health. As technology continues to evolve, future enhancements may include advanced analytics and intelligent decision-support features to further improve system performance and adaptability. Through continuous development and innovation, AquaTrack contributes to the modernization and sustainability of bangus farming operations.

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