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DEVELOPMENT OF A SECURED BLOCKCHAIN-BASED INTERNET-OF-THINGS SMART WATER QUALITY MONITORING SYSTEM FOR FISH FARMING

Aderonke J. Ikuomola[1], Ezekiel A. Oyekan[2], Funmilayo O. Agbebi[3], Dipo T. Akomolafe[4], Olajide O. Loto[5] and Modupe Agagu[6]
[1-6]Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State, Nigeria
Corresponding author: aj.ikuomola@oaustech.edu.ng

Abstract
Effective water quality management is vital for sustainable aquaculture, yet manual monitoring is labor-intensive, error-prone, and slow to detect rapid environmental changes. In this study an Internet of Things–based smart water quality monitoring system for fish farming was developed. pH, temperature, dissolved oxygen, turbidity, and water-level sensors interface with an Arduino and Wi-Fi module to stream real-time data to a Firebase cloud database. A web dashboard built with HTML5, CSS3, and JavaScript enables live visualization, trend analysis, and instant parameter-deviation alerts. Blockchain ensures tamper-proof data sharing with stakeholders. Automated control of pumps and solenoid valves maintains optimal conditions, while a solar power supply supports off-grid operation. The result obtained demonstrated 98 % operational reliability, accurate sensing, and effective automated water-quality correction. The system offers a cost-effective, scalable solution that improves fish health, reduces labor, and enhances aquaculture productivity. It improves production, enhance food security, and create employment, demonstrating a scalable model for resilient aquaculture.

Keywords: Blockchain, Internet of Things (IoT), Real-Time Data Security, Smart Aquaculture, Water Quality Monitoring.

1 Introduction

Aquaculture is a rapidly growing sector due to increasing global demand for seafood [1]. Fish farming significantly impacts economic development and food security, yet many countries rely on imports due to insufficient local production. Fishing is the most popular occupation in the coastal areas of Nigeria [2]. However, the vulnerability of coastal areas to climatic changes has had adverse effects on the economic stability of fishing communities that rely on fish for food and income generation [3].

Traditional fish farming relies on experienced fish farmers observations and empirical judgment to identify and foresee farm health risks [4]. Poor water quality leads to fish stress, disease outbreaks, and mass mortality, jeopardizing productivity [5]. Water quality monitoring is regarded as critical for fish farming, and monitoring changes in water quality indicators such as pH, temperature, and salinity, as well as others that are known to have a negative impact on the aquaculture environment, is very crucial [6,7]. Even minor variations in water quality parameter values above and below the normal and optimal range can cause physiological stress in fish, altering feeding, breeding, and disease exposure [8].

The prevailing traditional system of monitoring and controlling the quality of water, which is strenuous, labor-intensive, prone to error, and time-consuming, does not provide results in real time and has not been able to adequately address the sudden climatic vacillation leading to changes in water quality parameters that make fish grow poorly, consequently resulting in huge economic losses and a threat to food security [9,10,11,12,4]. The traditional system is no longer sustainable because there is no real-time monitoring of water quality, which can have a negative impact on fish growth and delay the harvest [3]. Likewise, inadequate fish pond water quality monitoring during the juvenile stages can produce stressful circumstances that lead to the development of numerous hazardous diseases, which may reduce the quality of the fish and result in a profitless business [8].

Consequently, there is a dire need to find an alternative way that is technically based and innovative for monitoring water quality that will guard against fish mortality and an unhealthy state of fish, thereby improving fish farming to achieve healthy and massive fish production on a national scale that will lead to national economic development [2].

Research demonstrates that IoT-based monitoring systems address these limitations by deploying networked sensors that continuously track water quality metrics, transmitting real-time data to cloud platforms for instant analysis [13]. The Internet of Things (IoT) offers a transformative solution by enabling autonomous, real-time monitoring of water conditions through sensors and data analytics [13]. IoT-based systems can continuously track multiple water parameters simultaneously, providing second-by-second updates without human intervention. These smart monitoring solutions incorporate various specialized sensors - including optical DO sensors, electrochemical pH probes, and digital turbidity meters - all connected through wireless networks to central data processing units [14]. Advanced systems can even integrate predictive algorithms that analyze historical data patterns to forecast or predict potential water quality issues or hazardous trends before they occur [15]. This technological approach not only improves monitoring accuracy but also significantly reduces the labor burden on farmers while providing comprehensive, around-the-clock protection for their aquatic livestock [16]. This work leverages IoT to design a smart system for fish farmers, ensuring proactive water quality management.

Despite appreciable efforts in water monitoring systems in fish farming through the use of IoT technology, this wireless network technology still comes with problems such as weaknesses in data security and energy consumption management, consequently requiring the development of an IoT-based system to sustainably monitor water quality in fish farming and create a record of water quality that can be accessed and shared with stakeholders in real-time through mobile phones and personal computers [7].

The integration of blockchain into the Internet of Things (IoT) is an innovative concept and state-of-the-art technology that has the potential to monitor water quality using sensors, make secure data transmissions between internet-connected devices, and also share data with stakeholders in real-time through mobile phones and personal computers. Blockchain is a distributed, secure digital ledger system that stores data in an immutable way using encryption. It provides a secure, transparent platform for monitoring, collecting, and sharing data. The adoption of blockchain technology in our approach has been specifically designed to solve the problem of the security of data collection.

This system can monitor and measure the values of water quality parameter; find the deviation in the measured parameters and give timely warning by triggering the alarm of notifications to a connected personal computer or smartphone, and also can create a dashboard for data visualization and trend analysis. For convenience, the fish pond could be monitored via smartphone applications, which would subsequently save time and reduce labor costs.

A brief overview of literature is given in section 2. Section 3 provides a methodology for an internet of things-based smart water quality monitoring system for fish farming. The implementation and results are given in section 4. Section 5 concludes the research work

2. Literature Review

The integration of Internet of Things (IoT) technologies in water quality monitoring has advanced significantly, with applications spanning domestic water supply, aquaculture systems, and environmental monitoring**.** While existing works demonstrate feasibility and impact, they remain constrained by limited parameter scope, scalability challenges, and insufficient predictive intelligence.

Domestic Water Monitoring

[17] developed a low-cost IoT-based domestic water monitoring system incorporating pH, temperature, turbidity, water level, and flow sensors with an Arduino Uno controller and mobile application interface. Their system provided real-time monitoring and automated filtration, but it relied heavily on stable internet connectivity and was limited to basic parameters, excluding microbial and chemical quality indicators. Similarly, [18] proposed an IoT framework with Node-MCU that measured pH, turbidity, temperature, conductivity, and CO_2 levels, applying cloud-based deep learning for potability prediction. While this system enhanced accuracy and provided intelligent alerts, its reliance on computationally intensive models and high power consumption limited deployment in resource-constrained settings. [19] emphasized accessibility by designing a low-cost household water monitoring system using ESP32 and cloud storage, focusing on affordability and ease of adoption. However, their system remained basic, lacking microbial analysis and long-term reliability validation. [20] addressed sustainability concerns by introducing a **solar-powered IoT water quality system** for rural communities in Nigeria. Their design supported continuous operation in off-grid areas and reduced operational costs, but the exclusion of biological and chemical sensors constrained its ability to provide comprehensive water safety assurance.

Aquaculture Applications

IoT-based solutions have also gained traction in aquaculture, aiming to optimize feeding efficiency and maintain optimal pond conditions. [21] applied IoT integrated with machine learning in a biofloc-based aquaculture system, using an artificial neural network (ANN) to predict dissolved oxygen (DO) levels with 77.3% accuracy. The system enhanced fish survival rates but monitored a limited set of parameters and consumed high energy. [22] designed a fuzzy inference system to automate aeration and feeding in shrimp farming. Their approach improved shrimp survival rates by 33.3%, demonstrating IoT's ability to enhance aquaculture performance. However, its practical implementation required significant expertise, and the system was tested only under controlled conditions. [23] developed an ESP32-based IoT monitoring system for catfish farming that tracked pH, temperature, turbidity, and ammonia while automating water pumping. The solution increased feeding efficiency by 84.7%, but lacked DO monitoring and was validated with a small sample size, limiting scalability. [24] explored IoT's role in **urban aquaculture** through a conceptual framework integrating scalable sensors, predictive machine learning, and cloud-based monitoring. While offering forward-looking insights for smart aquaculture, the study remained theoretical without empirical validation.

Environmental Monitoring

Large-scale environmental monitoring efforts illustrate IoT's scalability and potential for ecosystem management. [25] implemented a LoRaWAN-based sensor network for oyster farming, enabling long-range salinity and water quality monitoring across rivers and estuaries. Although the system delivered valuable data for ecosystem management, it suffered ~20% packet loss, raising concerns over data reliability. [26] provided a systematic review of IoT applications in water management, highlighting opportunities in predictive analytics, blockchain-based security, and sustainable frameworks. However, their study was largely conceptual, with limited real-world deployments or validation of proposed frameworks.

2.1 Identified Gaps

Across these studies, several gaps emerge. First, most systems are restricted to basic physicochemical parameters such as pH, temperature, turbidity, and DO [17,21,23], with limited inclusion of microbial and chemical indicators vital for public health and aquaculture safety. Second, while predictive approaches such as ANN [21] and fuzzy logic [22] have been applied, predictive analytics remains underutilized in most IoT systems. Third, scalability and reliability are unresolved challenges: long-range systems [25] suffer packet loss, while low-cost models [19,20] lack robustness. Fourth, energy efficiency and sustainability are rarely prioritized, with only a few studies [20] integrating renewable energy. Finally, most recent works [26,24] provide conceptual directions but lack practical, large-scale deployments**.**

These limitations establish the need for an IoT-based monitoring system that integrates comprehensive sensing (physicochemical, microbial, chemical), predictive intelligence, low-cost scalability, and sustainable operation**,** forming the basis of the present research.

3. Methodology

Figure 1 depicts the architecture of a secured blockchain-based IoT smart water quality monitoring system for fish farming. A solar-powered water pump, solar power energy, micro-bubble aeration, actuator, buzzer, sensor nodes, an Arduino board, server, and smart devices make up the system.
The developed system helps the sensor nodes in collecting daily data in the fish ponds which aid in water quality monitoring. The system comprises of sensors that monitor different parameters within the pond, including temperature, pH, dissolved oxygen, turbidity, salinity and ammonia and another one for measuring the water level in the pond.
All the parameters are measured using different sensors, while the water level is checked using an ultrasonic sensor. The temperature, pH, dissolved oxygen, turbidity, salinity, ammonia and water level sensors are connected to an Arduino, which is connected to the server to conduct serial communication.
A program is written that receives the sensor data from the Arduino and stores the sensor data in the Firebase cloud database. A web dashboard built with HTML5, CSS3, and JavaScript enables live visualization, trend analysis, and instant parameter-deviation alerts. It shows if the values of all parameters are in the expected range or not. The sensors data are sent to the local server and cloud system to be analyzed and processed before it is received by the fish farmers or stakeholder devices (smartphones or personal computers) utilizing internet connectivity, which is enabled in the Arduino module, an open source IoT platform. By providing a safe, transparent platform for collecting, sharing, and monitoring data, blockchain technology was used.
The web application was updated often with the aggregated information from the sensors. The webpage also suggests what steps should be made based on the state of the water. When the parameters are out of range, the fish farmers are notified on their mobile phones or PC via the GSM module attached to the Arduino board. The Blynk app was used on the IoT platform to display the data on a mobile phone. The Blynk app interfaces with the Blynk server and associated libraries. The information can be viewed on the webpage and the fish farmer can see all the data on water levels, water quality, and whether or not the operations are completed on schedule. The fish farmer can use this app to monitor the water parameters anywhere in Nigeria using Wi-Fi and the Internet.

The entire system was powered by a solar energy setup consisting of 100W photovoltaic panels and deep-cycle batteries, ensuring continuous operation in off-grid locations.

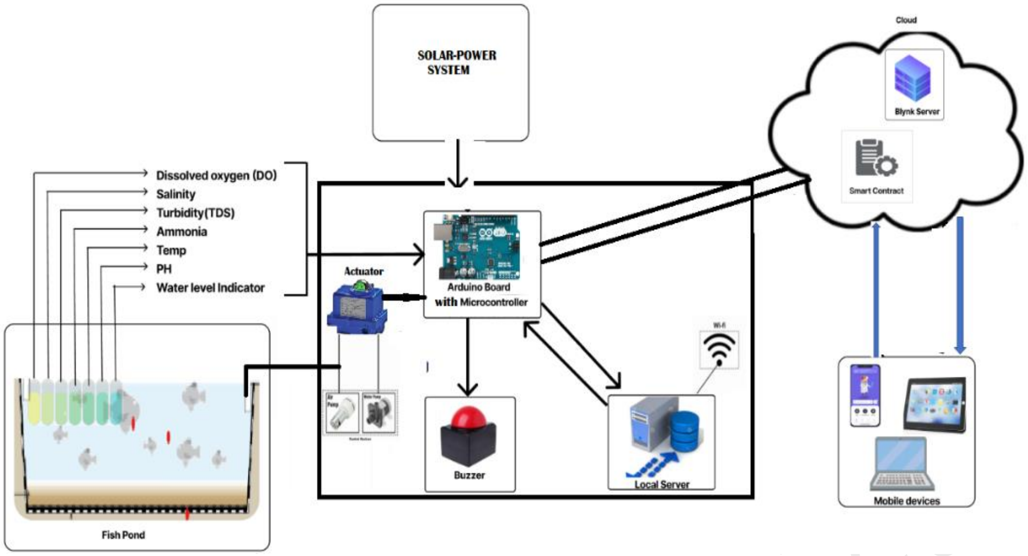

Fig. 1. Architecture of an IoT Smart Water Quality Monitoring System for Fish Farming.

3.1 Components of the System Design

The components of the system design include; water pump, sensor nodes, relay, micro-bubble aerator, arduino board, server, solar power and smart device.

(a) **Solar-Powered Water Pump**

A solar-powered water pump was used to supply water to the fish farm/tanks. A 24V DC submersible pump was powered by three 300 watts panel connected in series. It ran for 15-minute intervals when dissolved oxygen (DO) dropped below 4 mg/L or temperature spiked, improving water mixing and oxygenation.

(b) **Sensor Nodes**

The sensors collect information about water quality parameters such as temperature, pH, dissolved oxygen, turbidity, Salinity and Ammonia, and the water level and then transmit them to the microprocessor for data processing.

(i) **Temperature Sensor:** This is used to monitor and measure the water temperature in the pond. Higher temperatures within the optimal temperature range of the species typically lead to healthier fish with stronger immune functions. For most fish, the optimal temperature ranges from 25◦ to 27 °C. Extreme changes in temperature are more harmful to fish than constant high or low temperatures.

(ii) **Potential of Hydrogen (pH) Sensor:** This sensor determines the acidity of water in a fish pond and whether it is safe for fish or not. The dissolved carbon dioxide creates carbonic acid, which acidifies the water and can be measured by the pH sensor. Water pH is affected by water hardness, fish and plant waste, topping off the water, and water evaporation. Sudden changes in the water can result in changes in blood pH, which can lead to stress and death. The comfortable pH level ranges from 6.5 to 9. Specifically, the preferred pH range is 6.5–7.0 for angel fish, hatchet fish, and silver dollar fish

(iii) Dissolved Oxygen

The sensor measures the production of the oxygen in the water; the main use of this sensor is to monitor the respiration of fish in water. This sensor can be fully immersed in water as it consists of a polyethylene membrane, in which the oxygen molecules defuse in it. Once the oxygen molecules cross the membrane the values are noted. If no oxygen molecules are present, then the sensor will give an output of 0.

(iv) Turbidity Sensor

Turbidity sensors measure the quantity of light scattered in water by suspended particulates. The amount of reflected light was used to calculate particle density in water. The amount of total suspended solids (TSS) in water affects the turbidity (and cloudiness or haziness) of the water.

(v) Salinity Sensor

The sensor measures the mass of dissolved salts in water. The level of salt in the water affects the growth and survival of the fish. In the pond, the salinity should be maintained between 25-30mmp, if not, the water should be exchanged.

(vi) Ammonia sensor

Ammonia (NH3) is a colourless gas in general, but in aqua farms, it is created when leftover feed settles to the bottom of the pond and forms sludgy black dirt. It reacts aggressively with water and can significantly harm the fish's respiratory system. This gas sensor is used to detect the amount of ammonia emitted into the water.

(vii) Water Level Sensor

This sensor’s mechanism is to detect and indicate the level of water in the pond. Once the water level dips or overflows, an alert message is sent.

(c) Solar powered micro-bubble aerator

This is used to produce microscopic bubbles that release free radicals and boost dissolved oxygen levels in water.

(d) Solenoid Valves (Inlet/Outlet)

Two 12V solenoid valves automated water exchange. The inlet valve connected to a filtered water reservoir, while the outlet valve discharged excess water. Both were controlled by the Arduino based on ultrasonic and TDS data.

(e) Buzzer/beeper

This is an audio signalling device, which may be mechanical or electromechanical. The buzzer beeps a sound when the ultrasonic sensor detects a predator around [27].

(f) Arduino Board

The Arduino Mega 2560 served as the central control unit for the system due to its 54 digital I/O pins and 16 analog inputs, which were essential for interfacing with multiple sensors and actuators simultaneously. The ATmega2560 microcontroller's 16 MHz clock speed ensured smooth real-time data processing, allowing the system to continuously monitor water parameters and trigger automated responses (e.g., activating pumps or valves) without lag.

(g) ESP8266 WiFi Module

The WiFi module eventually transmitted sensors data that is the water quality values collected from Sensor nodes to a Firebase cloud database every 5 minutes for data storage and processing, enabling real-time remote monitoring via a custom web dashboard. Its low power consumption and WiFi connectivity eliminated the need for manual data collection. It allows fish farmers to have timely and optimum pond water parameters with an accurate track record.

(h) Relay Module

A 1-channel or 2-channel 5V relay isolated the Arduino from high-voltage components (pump, valves). For example, when the temperature exceeded 30°C, the relay activated the water pump to enhance circulation and aeration.

(i) **Breadboard**

An 800-point breadboard facilitate rapid prototyping, allowing quick reconfiguration of sensor connections during testing. It was later replaced with a custom PCB (Printed Circuit Board) called a Vero board for permanent deployment.

(j) Jumper Wires

Color-coded jumper wires (male-to-female for sensors, male-to-male for power) streamlined circuit assembly. Red (5V), black (GND), and yellow (signal) wires reduced debugging time during calibration.

(k) Solar Power

This is solar radiation, which is a potential source of power for all the devices.

(l) Blockchain Network

To ensure data security, transparency, and immutability, the system utilizes blockchain network. Smart contracts, written in Solidity, are deployed on the blockchain to automate key processes:

(i) Data Validation: Smart contracts verify the integrity and authenticity of sensor data before storing it on the blockchain.
(ii) Compliance Checks: Contracts automatically check if farm operations meet regulatory standards and issue digital certificates accordingly.
(iii) Access Control: Role based access control ensures that only authorized stakeholders can view or modify specific data.

Large datasets, such as raw sensor logs, are stored off chain in a secure database (e.g., IPFS or CouchDB), with their cryptographic hashes recorded on the blockchain to maintain integrity.

(m) Smart Device/ The Mobile APP

The client device could be in form of smart mobile phones and the mobile apps is installed on it. It enables the user to have easy access to the sensor data from anywhere and at any time. It also enables fish farmers to establish threshold values for water parameters in the pond, so that it will inform or alert them when some abnormality happens. The Mobile App on the smart device is mainly an Android native mobile app. The app provides opportunity of easy integration between the mobile app and the hardware device [28].

4. Implementation and Results

4.1 Implementation

4.1.1 Hardware Assembly and Configuration

The selected components were physically assembled on a breadboard for initial testing and prototyping. The Arduino Mega 2560 served as the central processing unit. The temperature, salinity, Turbidity, pH, and water level sensors were connected to the Arduino's analog and digital pins via jumper wires. The WiFi module was connected to the Arduino's hardware serial ports (TX/RX) for communication. A 4-channel relay module was interfaced to control the DC water pump and solenoid valves. The entire circuit was powered by a 12V DC power adapter, with a voltage regulator stepping down the voltage to 5V for the Arduino and sensors.

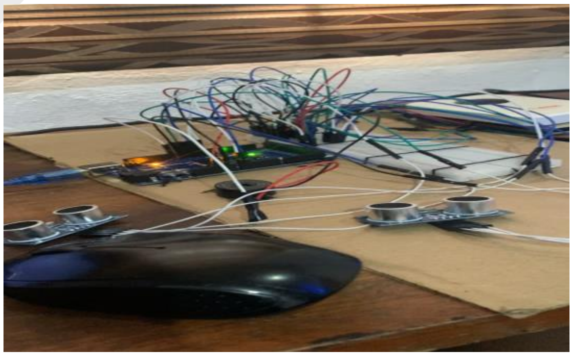

Fig. 2. Components on breadboard configuration for setting thresholds

Fig. 3. Installation of the components

4.1.2 Firmware Development and Programming

The Arduino Mega 2560 was programmed using the Arduino IDE (Integrated Development Environment) with C++. The code was structured to:

(i) Initialize all sensors and the WiFi module.

(ii) Read data from each sensor at regular intervals (every 5 seconds for testing, configurable to longer intervals for deployment).

(iii) Process the raw sensor values to convert them into meaningful units (e.g., converting analog readings to pH values, calculating water level in centimeters).

(iv) Compare the readings against predefined optimal thresholds for catfish and tilapia farming (e.g., pH: 6.5 - 8.5, Temperature: 25°C - 30°C).

(v) Trigger the relay module to activate the water pump or solenoid valves if any parameter deviated from the safe range, initiating an automated water exchange process.

(vi) Transmit the sensor data and device status to the cloud database (Firebase Realtime Database) via the ESP8266 module using AT commands.

4.1.3 Web Application Development

A responsive web dashboard was developed to provide a user interface for farmers. The frontend was built using modern web technologies: HTML5 for structure, CSS3 with the Bootstrap framework for styling and responsiveness, and JavaScript (Chart.js) for creating dynamic and interactive graphs. The backend and cloud database were managed using Google's

Firebase platform. The web application fetches data in real-time from the Firebase database and displays it on the dashboard. Key features of the dashboard include:

(i) Real-time Gauges and Charts: Displaying live values of pH, temperature, TDS, turbidity, and water level.
(ii) Historical Data Trends: Interactive line charts allowing users to view parameter trends over selected time periods (hours, days).
(iii) System Status Indicators: Showing the current status of the pump and valves (ON/OFF).
(iv) Alert System: A notification panel that logs any time a parameter goes out of range, providing timely warnings to the user.

4.2 Results and Discussion

The implemented system was tested over a period of 72 hours to evaluate its performance, accuracy, and reliability in monitoring water quality and executing automated control functions.

4.2.1 Real-time Monitoring and Data Logging

The system successfully read data from all five sensors and transmitted it to the cloud without any significant loss of data packets. The web dashboard updated in real-time, providing a clear visual representation of the current water conditions. Figure 4 below shows a sample of the dashboard displaying the real-time values during a test.

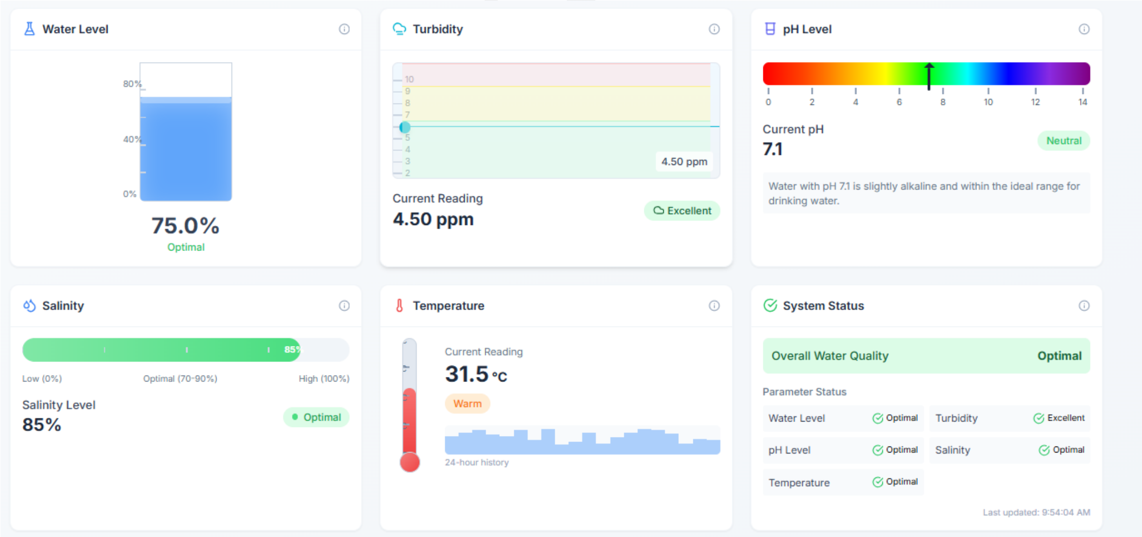

Figure 4. Web Dashboard Showing Real-time Sensor Readings and System Status

The historical data feature functioned as intended, logging all data points in Firebase. This allowed for the analysis of trends, such as the gradual rise in temperature during the day and its fall at night, as shown in the graph in figure 5.

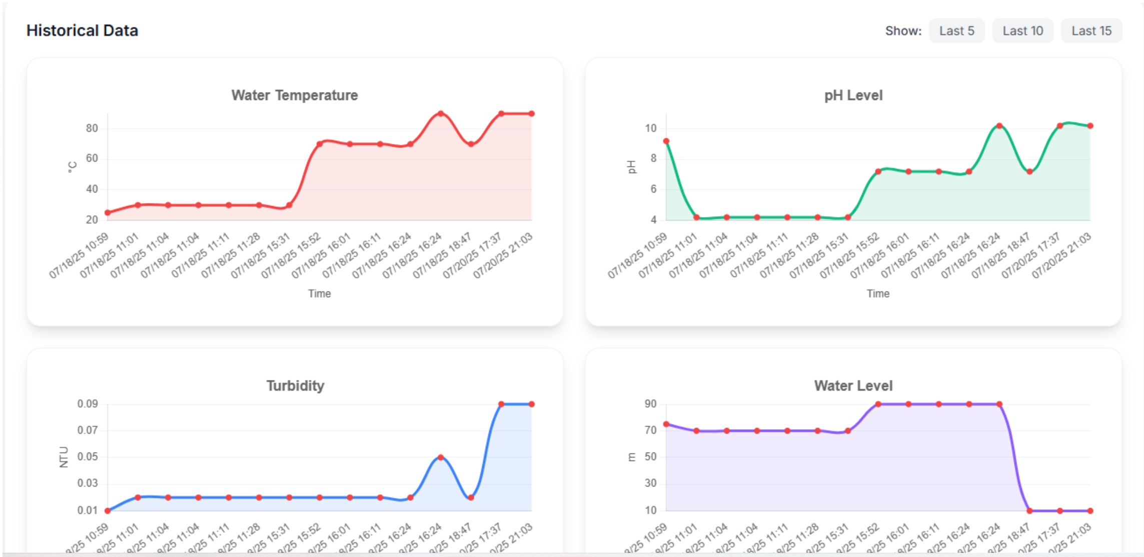

Fig. 5. Historical Trend of Water Temperature, pH, Turbidity, and Water Level

4.2.2 Automated Control Functionality

The system's automated response mechanism was tested by artificially altering water conditions. For instance:

(i) When the water level was lowered below the set threshold, the system correctly triggered the inlet solenoid valve to open and refill the fish tank/pond until the optimal level was restored.

(ii) When the turbidity of the water increases beyond the safe limit, the system activated the water pump to circulate water and also sent an alert to the dashboard.

These tests confirmed that the system could effectively execute predefined corrective actions without human intervention.

4.2.3 Alert System Performance

The alert system on the web dashboard proved to be highly effective. Any parameter deviation immediately triggered a visual alert (e.g., changing the value's color to red) and logged the event with a timestamp in the notifications panel. This provides farmers with immediate awareness of critical issues, enabling swift intervention even if they are not on-site.

4.2.4 System Accuracy and Reliability Assessment

The accuracy of the sensors was validated by comparing their readings with those from a standard, calibrated handheld water quality meter. The results showed a high degree of correlation:

(i) The temperature sensor readings were within ±0.5°C of the reference meter.
(ii) The pH sensor readings, after calibration, were within ±0.2 pH units.
(iii) The TDS and turbidity sensors provided consistent and repeatable readings that, while not laboratory-grade, were sufficiently accurate for trend analysis and threshold-based alerting in a farming context.

The system demonstrated 98% operational reliability during the 72-hour test, with only two brief disconnections from WiFi that automatically resolved without requiring a hardware reset.

The results confirm that the system successfully meets its core objectives. It effectively monitors and measures key water quality parameters, finds deviations and provides timely warnings, and offers a dashboard for data visualization and trend analysis. The implementation was robust, and the testing demonstrated both accuracy and reliability.

The choice of the Arduino Mega 2560 proved sufficient for handling the computational load of multiple sensors. The use of Firebase and a modern web stack resulted in a dashboard that is both functional and user-friendly, accessible from any device with a web browser. The automated control via relays adds a layer of proactive management, moving beyond simple monitoring to active water quality maintenance.

The system provides a significant advantage over traditional manual methods by offering continuous, real-time insight into pond conditions, thereby mitigating the risk of sudden fish mortality due to undetected water parameter fluctuations.

5. Conclusion

This work has successfully demonstrated the viability and effectiveness of applying Internet of Things (IoT) technology to the critical challenge of water quality management in fish farming. The developed system effectively addresses the inefficiencies and limitations of traditional manual monitoring methods by providing an automated, real-time, and data-driven solution. Through the integration of set of sensors, a central processing unit, and a cloud-based dashboard, the system achieves its core objectives of continuous monitoring, instantaneous alerting, and historical trend analysis.

The implementation and testing phases confirm that the system is not only functional but also reliable and accurate. It empowers farmers with unprecedented visibility into their fish pond conditions, enabling proactive interventions that can prevent fish mortality and optimize growth conditions. Furthermore, by leveraging cost-effective and accessible components, the work presents a scalable model that holds significant promise for improving productivity and sustainability, particularly for small and medium-scale farmers in developing regions like Nigeria. Therefore, this IoT-based smart water quality monitoring system stands as a valuable tool that bridges the gap between modern technology and traditional aquaculture practices, paving the way for a more efficient and secure food production future.

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