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Internet Of Things (IoT) Solutions For Precision Aquaculture Management System

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Abstract
Aquaculture is emerging as a vital contributor to global food security, yet its sustainability and profitability are hindered by inefficiencies in water quality management, disease detection, and feeding practices. This research was proposed to design and implement an Internet of Things (IoT)-based Precision Aquaculture Management System, integrating real-time monitoring, intelligent decision-making, and automation to revolutionize aquaculture operations. The system employed a multilayered architecture consisting of a perception layer equipped with water quality sensors (pH, temperature, dissolved oxygen, turbidity, ammonia) and biosensors for health analysis. These devices interfaced with ESP32 based microcontrollers and communicated via Wi-Fi to an edge processing unit (Raspberry Pi or Jetson Nano), which handled initial data filtering, local analytics, and real-time alerts. Data was transmitted to a cloud-based platform (e.g., AWS IoT or Firebase), where advanced machine learning algorithms were employed for predictive analytics such as detecting abnormal environmental conditions, forecasting disease outbreaks, and optimizing feeding schedules. The system integrated an automated feeding mechanism, triggered by real-time environmental conditions and fish activity patterns, thereby reducing feed wastage and improving feed conversion ratios. The platform also includes a decision support system capable of recommending corrective actions and generating alerts via SMS or email. Experimental validations and pilot deployments demonstrated significant improvements in operational efficiency, water quality stability, and fish health monitoring accuracy. This research contributed a scalable, data-driven framework for modern aquaculture management and paved the way for more sustainable, intelligent, and autonomous fish farming systems.

Keywords: *Internet of Things, Aquaculture Management, Sensors, ESP32 Microcontrollers, Precision Aquaculture, Thermometer.*

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I. Introduction

Aquaculture, the farming of aquatic organisms such as fish, crustaceans, mollusks, and aquatic plants, has evolved into one of the fastest-growing sectors in food production worldwide (Ahmed and Turchini, 2021). According to the Food and Agriculture Organization (FAO) report, aquaculture accounted for more than 50% of the global fish supply for human consumption as early as 2018, and this figure has continued to rise (FAO, 2020). The expansion of aquaculture has been largely driven by the increasing demand for high-protein diets, urbanization, and overfishing of natural water bodies. Particularly in Asia and Africa, aquaculture plays a critical role in food security and employment generation (Ahmed and Turchini, 2021). Despite its remarkable growth, the industry faces significant sustainability challenges, including environmental degradation, disease management, and resource efficiency (Ahmed and Turchini, 2021; Samson, 2021).

One of the principal challenges confronting the aquaculture industry today is the heavy reliance on manual operations. In many small and medium-scale farms, feeding is still performed manually, leading to inconsistencies in feed distribution and wastage (Samson, 2021). Manual monitoring of water quality parameters, such as dissolved oxygen and pH levels, is labor-intensive and prone to human error, which can compromise fish health and growth performance. Furthermore, disease outbreaks remain a substantial threat, often resulting in massive economic losses. For instance, infectious diseases such as Tilapia Lake Virus (TiLV) and various bacterial infections have caused significant mortality rates in aquaculture systems across different regions (Surachetpong *et al*., 2020). Feeding inefficiency is another pressing issue; poor feeding strategies not only escalate production costs but also contribute to water pollution due to excess nutrient deposition, thus deteriorating the aquatic environment (Gao *et al*., 2021).

In response to these challenges, the emergence of the Internet of Things (IoT) and smart farming technologies offers promising avenues for transformation. IoT enables the collection and transmission of real-time data through interconnected sensors, devices, and platforms, allowing farmers to monitor and control aquaculture systems remotely (Patil *et al*., 2019). Smart aquaculture incorporates technologies such as automated feeders, water quality monitoring sensors, machine vision for fish behavior analysis, and predictive analytics powered by artificial intelligence. These innovations facilitate continuous observation of environmental conditions and animal health, enabling timely interventions that improve productivity and reduce resource wastage (Kim *et al*., 2020; Patil *et al*., 2019). Consequently, IoT is poised to enhance operational efficiencies, lower labor costs, and foster more sustainable practices within the aquaculture sector.

The major contributions of this study are:

i. Develop a real-time water quality monitoring system using IoT sensors.
ii. Implement an automated water discharge and refill system using IoT Sensors
iii. Implement an automated Feeding system.

Problem statement

i. One of the major challenges in aquaculture today is the persistent inefficiency in feed utilization. Feed constitutes the largest operational cost in aquaculture, accounting for up to 70% of total production expenses (Gao *et al*., 2021).
ii. Delayed detection of poor water quality and fish diseases is another critical problem that affects aquaculture productivity. Water quality parameters such as dissolved oxygen, pH, ammonia concentration, and temperature can fluctuate rapidly, posing immediate risks to aquatic organisms if not addressed promptly (Abdul Salam *et al*., 2020).
iii. The lack of integrated platforms for precision aquaculture management further compounds operational inefficiencies. Many existing farms utilize fragmented systems for feeding, monitoring, and health management, with little or no interoperability between devices and data sources (Patil *et al*., 2019).

Related Works

A summary of the literature was presented in Table 1, considering the most recent and closest works, and then making findings to establish the research gap.

Table 1: Summarized review of related works

Authors	Research Area	Methodology	Result	Gap
Ahmed &Turchini, 2021	Water Quality Management	IoT Technology	Notify the Sensor when to change Water	Does not automatically refill and discharge the water
Rosa *et al*., 2021	Fish behavior during Eating	IoT Technology	Automated, monitoring Fish behavior during Feeding	Does not automatically refill and discharge water
Luo *et al*., 2022	Fish Health	IoT Technology	biosensors, imaging Technologies	Monitors the water Level Monitoring

II. Materials And Methods

This section provides a detailed overview of element acquisition, preparation, integration, proposed model architectures, and operations.

Materials

Aquaculture infrastructure: Freshwater earthen pond (300 m²), *Clarias gariepinus* (African catfish) fingerlings, paddle wheel aerator, belt-driven automatic feeder, inlet and outlet water control channels.

Sensors and monitoring devices: Dissolved oxygen (DO) sensor (analog type). Digital pH sensor module, temperature sensor (DS18B20 waterproof), ammonia (NH_3) sensor module, turbidity sensor, underwater surveillance camera (IR/night-vision capable).

Microcontrollers and communication modules: ESP32 development boards, arduino Uno microcontrollers, LoRa SX1278 transceivers (long-range wireless communication), Relay modules (for actuator control).

Edge and cloud computing components: Raspberry Pi 4 model B (edge gateway), MicroSD card (32 GB) for RPi storage, Wi-Fi/Ethernet router, Solar battery backup (12V DC system), Laptop/PC for cloud access.

Software and Data Tools: Python (programming logic and control), Node-RED (IoT flow programming), InfluxDB (sensor data storage), Grafana (real-time dashboard), Scikit-learn and TensorFlow (AI model training), OpenCV (computer vision and motion tracking), and Telegram Bot API (alert notifications).
Manual measurement tools: Measuring board (for fish length), Electronic weighing scale, Digital thermometer, and Fish net, scoop, and sampling containers

Study Area

The experimental phase of this research was conducted in **Abakaliki,** the capital city of **Ebonyi State,** located in the southeastern region of Nigeria. The city serves as the administrative and economic hub of Ebonyi State and is characterized by a growing emphasis on agriculture, including fish farming, rice production, and poultry.

Automated water control system in aquaculture management system.

This is the diagrammatical representation of the system which contains the fish pond, the sensors, and the water control system.

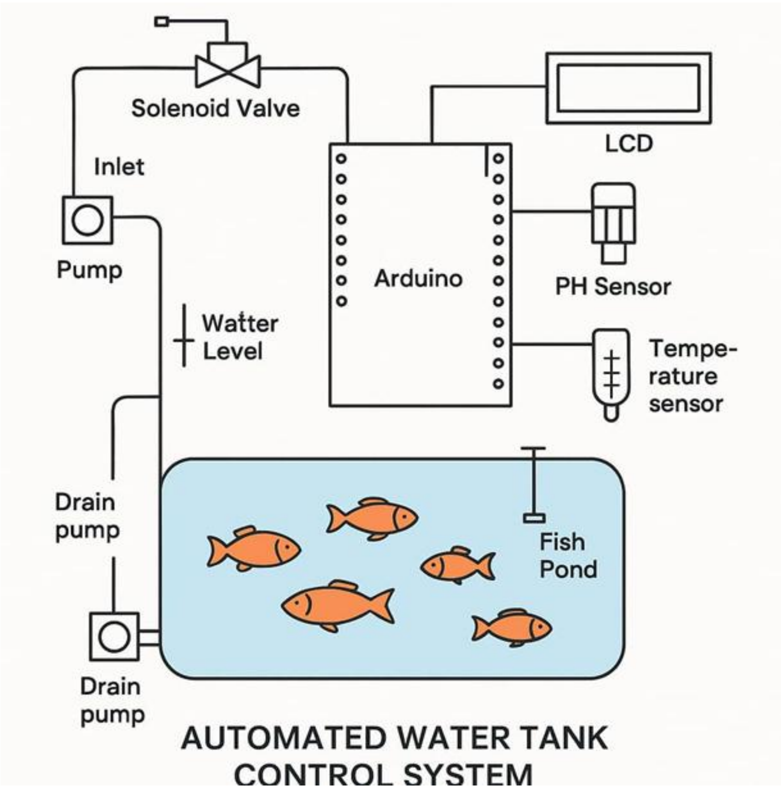

Figure 1: Automated water control system in aquaculture management system.

Overview of the IoT System in Aquaculture

An **IoT (Internet of Things) system in aquaculture** integrates **sensors, devices, networks, and cloud platforms** to enable **real-time monitoring, data-driven decisions,** and **automated control** of fish pond operations. It supports **precision aquaculture** by enhancing efficiency, reducing losses, and optimizing resource usage.

Table 2: Core Components of an IoT-Based System

Component	Function
Water Quality Sensors	Monitor pH, temperature, dissolved oxygen (DO), ammonia, turbidity, etc.
Smart Feeders	Automatically dispense feed based on schedule or fish behavior
Cameras / Vision Systems	Monitor fish health, movement, feeding behavior, or estimate biomass
Edge Devices Microcontrollers	Collect and transmit sensor data; perform local processing
Actuators	Control aerators, water pumps, feeders, etc., based on sensor input
Communication Network	LoRa, NB-IoT, Wi-Fi, or cellular network to send data to a central system

Component	Function
Cloud Platform / Server	Store data, run analytics/AI models, and host user interfaces
Uer Interface	Dashboard or mobile app for monitoring, alerts, and manual overrides

Advantages of the IoT System

Table 3: Advantages of the IoT System

Area	Advantage
Real-Time Monitoring	24/7 data collection for faster response to problems
Precision Feeding	Minimizes feed waste, improves growth rates, and reduces FCR
Improved Fish Health	Early detection of stress or disease through sensors and behavior analysis
Labor Savings	Reduces need for constant human presence
Data-Driven Decisions	Allows informed decisions based on historical trends and predictive models
Automation	Systems like aerators and feeders operate automatically
Remote Access	Monitor and control the farm from anywhere using a phone or computer
Better Record Keeping	Digital logs ensure data accuracy and easy access to performance reports

Use Case Diagram

Use Case Diagram description for the **IoT-Based Precision Aquaculture Management System** along with the actors and main use cases.

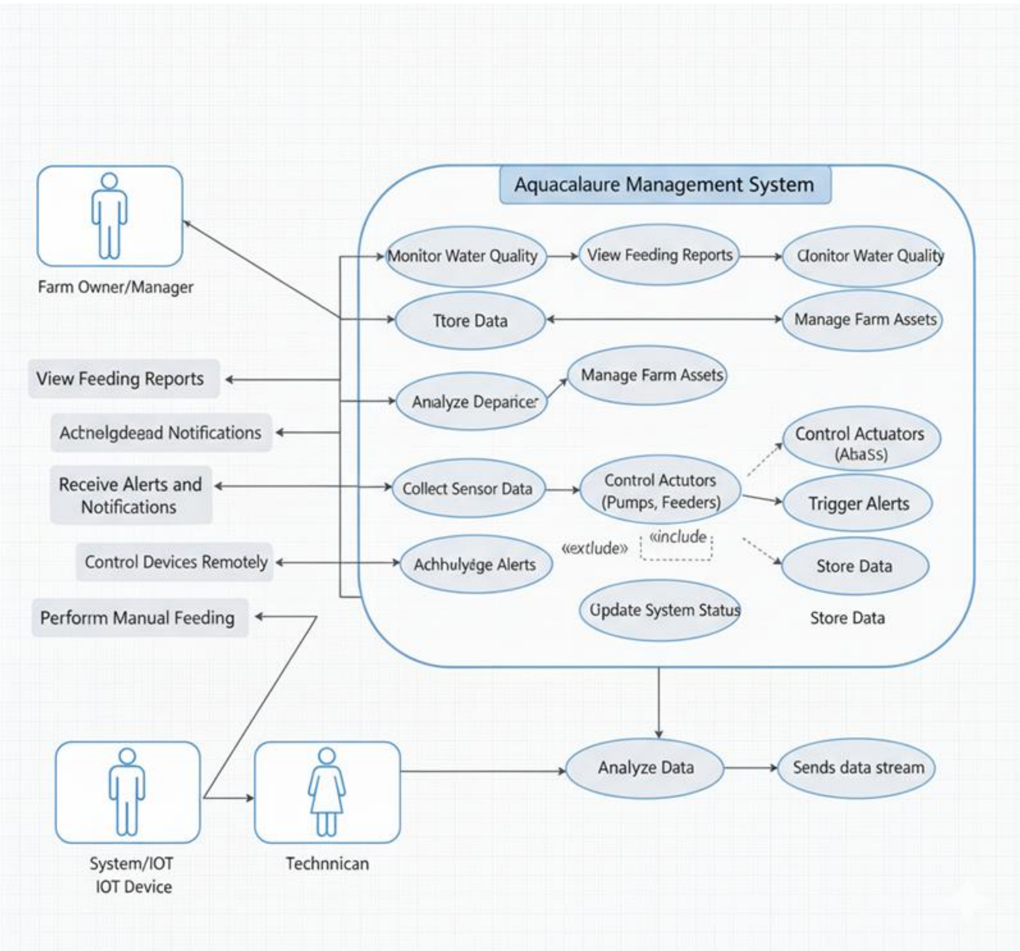

Fig. 2. Use case diagram of IOT Aquaculture management system

A **use case diagram** for an IoT solution in aquaculture management system outlines the interactions between different users (actors) and the system. It shows what the system does from the user's perspective. Here is a breakdown of the key components of such a diagram.

Actors

- **Farm Owner/Manager**: This is the primary user responsible for overseeing the entire operation. They manage all aspects of the farm and need to make informed decisions.
- **Technician/Operator**: This user is responsible for the day-to-day physical tasks on the farm, such as feeding, maintenance, and responding to alerts.
- **System/IoT Device**: This "actor" represents the automated part of the system, including sensors, controllers, and the cloud platform. It acts independently to collect data and perform automated tasks.

Use Cases

The following are the main use cases for each actor, demonstrating their specific functions within the system.

Use Cases for Farm Owner/Manager

- **Monitor Water Quality**: The owner can view real-time data from sensors to monitor critical parameters like pH, dissolved oxygen, temperature, and ammonia levels.
- **View Feeding Reports**: They can access logs and reports on feeding schedules and consumption to optimize feed usage and reduce waste.
- **Manage Farm Assets**: This includes setting up new ponds, tanks, or pens within the system, and configuring the sensors and devices associated with them.
- **Receive Alerts and Notifications**: The system notifies the owner of critical events, such as a drop in oxygen levels or an equipment malfunction.
- **Control Devices Remotely**: The owner can remotely adjust parameters, like turning on aeration pumps or activating feeders from a dashboard.
- **Generate Reports and Analytics**: The system allows the owner to create and analyze historical data to identify trends, predict issues, and plan for future operations.

Use Cases for Technician/Operator

- **Perform Manual Feeding**: The technician can log when and how much they manually feed the fish.
- **Acknowledge Alerts**: They can receive and respond to alerts from the system regarding any issues that require physical intervention.
- **Update System Status**: The technician can update the system about completed tasks, such as equipment maintenance or water changes.

Use Cases for the System/IoT Device

- **Collect Sensor Data**: This is a fundamental, automated use case where sensors continuously gather data on water quality.

Activity Diagram

Activity Diagram description for the **IoT-Based Precision Aquaculture Management System** — it outlines the flow of activities from monitoring to control and user interaction.

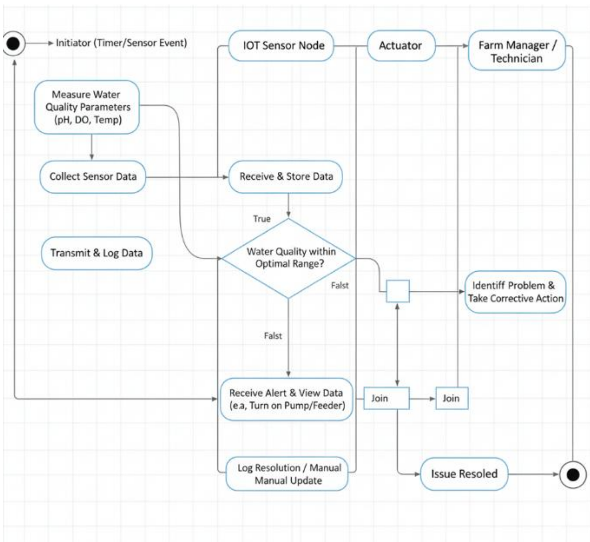

Fig. 3: an activity diagram for an IoT solution for an aquaculture management system

an **activity diagram** for an IoT solution for an aquaculture management system, which illustrates the flow of control and actions from data collection to decision-making and automated responses.

Activity Diagram for an IoT Aquaculture Management System

The diagram below shows the sequential and parallel activities involved in the system's operation. The process begins with continuous data collection and leads to various actions, including alerts and automated controls.

1. Data Collection & Monitoring The activity starts with the **IoT sensors** in the pond or tank. These sensors continuously **measure water quality parameters** such as pH, temperature, dissolved oxygen, and ammonia levels. This data is then **transmitted** to a central hub or cloud platform.

2. Data Processing Once received, the **system processes the data** and compares the current readings against predefined optimal or threshold values.

3. Decision-Making & Alerts This is a critical point in the flow. The system enters a decision node:
- **If water quality is within optimal range**: The system continues to monitor and **store the data** for historical analysis and reporting.
- **If a parameter is outside the optimal range**: The system proceeds to trigger an alert.

4. Automated & Manual Response The system then determines the necessary response.
- **Automated Response**: For critical issues like low dissolved oxygen, the system automatically **activates actuators** such as aeration pumps or water circulators to correct the parameter.
- **Trigger Manual Alert**: The system also **sends a notification** to the farm manager or technician via SMS, email, or a mobile app. This parallel action ensures human intervention is possible.

5. Human Intervention & Resolution Upon receiving the alert, the **farm manager or technician** can perform several actions:
- They **view the real-time data** on their dashboard.
- They **identify the problem** and its severity.
- They may take **corrective action**, which could involve manually adjusting a feeder, performing a water change, or physically inspecting the equipment.

The activity concludes once the issue is **resolved** and water parameters return to a healthy range, at which point the system loops back to the monitoring phase.

III. System Design And Implementation

Configuring Blynk App for ESP-32

To set up a Blynk IoT App for the smart system, the app is first downloaded from the Play Store for Android users and the App Store for iOS users. Once the installation is complete, open the app and **sign-up** using your email address and password.

a. Click on create a new project
b. Provide the Name of your project *as* "Enhanced IOT Ffor Precision Aquaculture"
c. Choose NodeMCU Dev Board
d. Select connection type as Wi-Fi, and then click on Create Button.
e. The Blynk authentication token is sent to your email address. (it is needed later on programming)
f. Now, click on the (+) icon at the top right corner of the screen.
g. Search for "Gauges" and add 2 of them to your main screen.
h. Click on the First Gauge.
i. Name it as "Aquaculture"
j. Set the Input Pin to Virtual Pin V1, Enter input Range & Choose the refresh rate as 1sec.

Similarly, do the same for *water condition***.**

Finally, the Blynk App setup for project using NodeMCU ESP8266 is completed.

Figure 14: Configuring Blynk App

When the code is uploaded, ESP-32 will connect to the Blynk server. Now you can check the Blynk app on your mobile phone. The mobile phone receives smart system data.

Software requirement
The smart system was implemented using some software tools which are listed below:
i. Arduino IDE: making a sketch and programming the microcontroller
ii. Micro C++: used as the main programming language.
iii. Fritzing software: used for component interfacing

Program Development
The system program was developed using Arduino IDE. This IDE enabled us to design a sketch (Write code) for the system. It also provides facilities for verifying (compiling) and uploading the code to the microcontroller for all control and sequencing functions.

The procedure is as follows:
1. Load Arduino IDE.
2. Create a new sketch and save it with a file name.
3. Design the sketch (write your control code).
4. Click on the verify button to compile the code. If errors were found, debug them and verify again.
5. Click on the upload button to upload (send) the sketch to the microcontroller. If there is port connection problem, debug it and try again.
6. Observe the system work according to your sketch.

Choice of Programming Language
The implementation of this Smart system was done in Embedded C/C++ Programming language. This language was chosen as it had been optimized for talking to machines. It is easier to access the pins on microcontrollers or other programmable chips and program them using c++ compared to other high level programming languages like java, c# etc. The main component of the proposed system that is programmed is the ATMEGA328P Microcontroller. The code (sketch) is written in C/C++, verified (Compiled) and finally uploaded to the chip for all control

Microcontroller Programming
The microcontroller is connected to the computer for programming through a 5V USB cable. Once the connection is made, the Microcontroller circuit will be detected by the computer and the actual port is selected by the programmer for programming operations.

System usage
The system shall be used as stated below:
1. The user presses the ON switch on the system to power it.
2. The system boots for few seconds and the sensors get activated.
3. The system develop a real-time water quality monitoring system using IoT sensors.
4. The system implement an automated feeding system based on environmental and behavioral data.
5. The user turns on his WiFi hotspot and the smart system automatically connects to the internet through the network.
6. Once connection is enabled, the sensor data will be sent to the user's mobile app interface in real time. The information will be displayed using gauge gadgets.
7. The system only displays the most recent value of the sensors on the mobile interface.

System construction tools
The system was constructed using the following materials:
a. A plastic casing with perforated holes for attaching the components. It was also purchased from the market.
b. Tools for perforation of holes: soldering iron and a stripper, a pencil and pen
c. Hot gun glue for holding the components fast onto the casing.
d. Screws and screw drivers.

Figure 3: System construction tools

System integration
All the components of the system have been put together in a casing and finished as shown below:

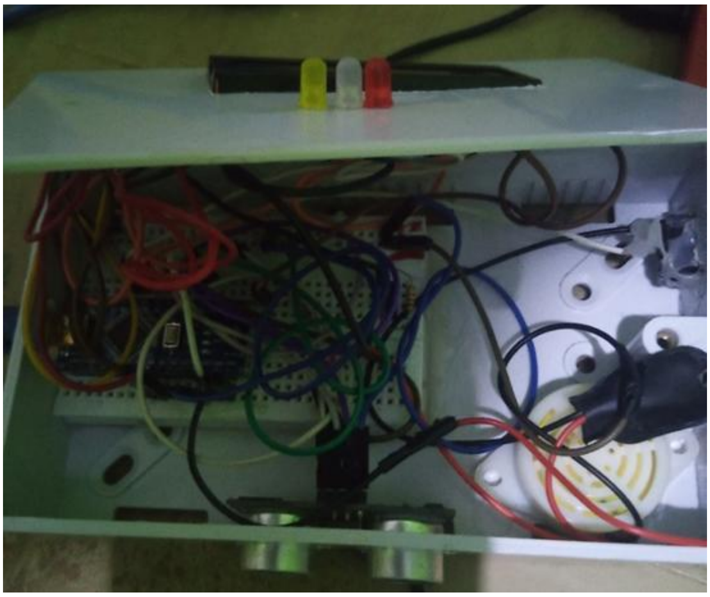

Figure 4: Inner Assembly of the System

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