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Automated Aquaculture System Using ESP32 with IoT for Efficient Water Quality and Feeding Management

Appala Sravan Kumar^{1*}, Nallella Shivani², Aluvala Vamshikrishna², Lenkala Manikanta², Pitta Sai Arun²

¹Assistant Professor, ²UG Student, ^{1,2}Department of Electronics & Communication Engineering

^{1,2}Vaagdevi Engineering College, Bollikunta, Warangal, 506005, Telangana, India.

*Correspondence: Appala Sravan Kumar (appala.sravan@gmail.com)

Abstract

The increasing demand for sustainable aquaculture and global fish production has led to significant technological advancements, with aquaculture contributing over 50% of the world's seafood supply and expected to grow at more than 5% annually. However, poor water quality and inefficient feeding practices account for nearly 30% of productivity loss in fish farming, emphasizing the need for intelligent monitoring systems. Traditional fish farming methods rely heavily on manual observation and periodic maintenance, which often leads to inconsistent water conditions, overfeeding or underfeeding, increased operational costs, and higher mortality rates. Additionally, the lack of real-time monitoring and data-driven decision-making reduces efficiency and sustainability. To address these challenges, the proposed IoT smart fish farming system utilizes the ESP32 microcontroller to enable an automated and intelligent aquaculture management solution. The system integrates temperature, humidity, and turbidity sensors to continuously monitor water conditions, while an RTC module ensures scheduled and precise feeding through an automated feed motor. Inlet and outlet pumps dynamically regulate water quality, maintaining a healthy aquatic environment. An LCD display provides real-time local visualization, and Bluetooth connectivity enables nearby monitoring, while IoT integration allows remote access, data logging, and control through cloud platforms. This smart system reduces manual intervention, enhances operational efficiency, improves fish health and productivity, and supports sustainable aquaculture practices through intelligent automation and real-time environmental management.

Keywords: Aquaculture Automation, Bluetooth Monitoring, ESP32, Feed Control System, Internet of Things, Smart Fish Farming, Turbidity Monitoring, Water Quality Management.

1. Introduction

The global demand for sustainable aquaculture has increased significantly as fish consumption continues to rise worldwide [1]. Aquaculture currently contributes to over 50% of the global seafood supply, and the sector is projected to grow at an annual rate exceeding 5%, driven by population growth and the need for reliable protein sources [2]. However, inefficiencies in farm management—particularly poor water quality and improper feeding—account for nearly 30% of productivity losses, posing a major challenge to the industry. With the advancement of smart agriculture and IoT technologies, there is an increasing need for

intelligent systems that can monitor and manage aquaculture environments in real time [3]. In practical applications such as commercial fish farms, hatcheries, and inland ponds, automated solutions are essential to ensure optimal water conditions, efficient feeding, and improved yield.

Problem Statement: Traditional fish farming methods largely depend on manual monitoring and periodic inspection of water conditions and feeding activities [4]. Farmers typically rely on experience rather than data-driven approaches to manage parameters such as temperature, turbidity, and feeding schedules. This lack of precision often leads to

inconsistent environmental conditions [5], which can negatively impact fish growth and health. Moreover, manual feeding practices can result in overfeeding or underfeeding, causing wastage of resources and increased operational costs [6]. Conventional systems also lack integration with modern communication technologies, preventing real-time monitoring and remote control, thereby limiting scalability and efficiency in large-scale aquaculture operations.

Motivation: In real-time scenarios, these limitations create several critical challenges that affect productivity and sustainability. Poor water quality due to delayed monitoring can lead to disease outbreaks, reduced oxygen levels, and increased fish mortality rates [7]. Inefficient feeding practices contribute to resource wastage and water pollution, further degrading the aquatic environment. Additionally, the absence of continuous monitoring and automated control prevents timely corrective actions, reducing overall farm efficiency. The lack of data analytics and remote accessibility also makes it difficult to optimize farming strategies. These challenges highlight the need for an intelligent, IoT-based system capable of real-time environmental monitoring, automated feeding, and adaptive control, ensuring improved fish health, enhanced productivity, and sustainable aquaculture practices.

2. Literature Survey

Boudhane et al. [8] proposed an underwater image processing method for fish localization and detection in submarine environments using enhancement and segmentation techniques. Li et al. [9] proposed a comprehensive review of automatic recognition methods for fish feeding behavior in aquaculture, covering image-based and sensor-based approaches. Desai et al. [10] proposed an image processing model integrated with deep learning for fish species classification using feature extraction and classification networks.

Delgado et al. [11] proposed a study on fish movement using acoustic telemetry and genomics to analyze behavioral and migration patterns in aquatic environments. The system integrated biological and sensing data for detailed movement analysis. Føre et al. [12] proposed a precision fish farming framework that incorporated sensing technologies, automation, and data analytics to improve aquaculture production. Delgado et al. [13] proposed an analysis of Northern cod movement using acoustic telemetry and genomic techniques to understand behavioral dynamics.

Zhao et al. [14] proposed a review on the application of machine learning in intelligent fish aquaculture, highlighting predictive modeling and automated monitoring systems. Vo et al. [15] proposed an overview of smart aquaculture systems focusing on machine learning and computer vision applications for monitoring and automation.

Brijs et al. [16] proposed biosensing technologies for aquaculture that enabled remote monitoring of fish health and environmental conditions. Zhang et al. [17] proposed an improved MobileNetV3-based model with multi-scale information fusion for fish feeding behavior analysis. Saberioon et al. [18] proposed a review of machine vision systems in aquaculture with emphasis on fish monitoring and analysis.

Boudhane et al. [19] proposed an underwater image processing method for fish detection using enhancement and segmentation techniques to improve detection accuracy. The system addressed challenges in underwater visibility and noise. Li et al. [20] proposed a review of automatic fish feeding behavior recognition methods that analyzed different sensing and image processing techniques for aquaculture monitoring.

3. Proposed System

Figure 1 represents an IoT-based smart fish farming system designed using an ESP32 microcontroller to monitor and control

essential aquaculture parameters in real time. The system integrates multiple sensors, including DHT11 for temperature and humidity, turbidity sensor for water clarity, pH sensor for acidity/alkalinity, ultrasonic sensor for water level detection, and an RTC module for time-based automation. These inputs are processed by the ESP32, which controls various actuators such as a feed motor for automated feeding, an inlet water pump for water management, and a buzzer for alerts. A 16×2 LCD provides local display of system status, while IoT connectivity enables remote monitoring and control through cloud platforms. This system ensures optimal water quality, timely feeding, and efficient farm management, thereby improving fish health, productivity, and operational efficiency.

Figure 2 represents the proposed working procedure. The detailed operation given as follows:

Step 1: Power Supply Initialization: The regulated power supply provides a stable voltage to the ESP32 controller and all connected sensors and actuators, ensuring reliable system operation.

Step 2: Sensor Data Acquisition: Sensors such as DHT11, turbidity, pH, ultrasonic, and RTC continuously collect environmental and water quality parameters including temperature, humidity, water clarity, pH level, and water level.

Step 3: Data Processing by ESP32: The ESP32 microcontroller processes the collected sensor data and compares it with predefined threshold values to determine the system condition.

Step 4: Decision Making and Automation: Based on the analysis, the ESP32 makes intelligent decisions such as activating the feed motor at scheduled times (using RTC), turning on the inlet water pump when water level or quality is inadequate, and triggering alerts if abnormal conditions are detected.

Step 5: Output Display and Alerts: The processed information is displayed on the LCD for real-time monitoring, while the buzzer provides immediate alerts during critical situations like poor water quality or low water level.

Step 6: IoT Communication and Remote Monitoring: All sensor data and system status are transmitted to the cloud via IoT, allowing users to monitor and control the fish farming system remotely using mobile or web applications.

Step 7: Continuous Monitoring and Optimization: The system operates continuously, ensuring optimal environmental conditions, improving fish growth, reducing manual effort, and enabling smart aquaculture management.



Figure 1. Block Diagram of ESP32-Based IoT Fish Farming Monitoring and Automation System.

Figure 3 depicts the complete circuit diagram of an ESP32-based IoT fish farming system designed for real-time monitoring and automated control of aquaculture parameters. The system is powered by a regulated power supply unit comprising a step-down transformer, bridge rectifier, filter capacitors, and a 7805-voltage regulator to provide a stable +5V output.

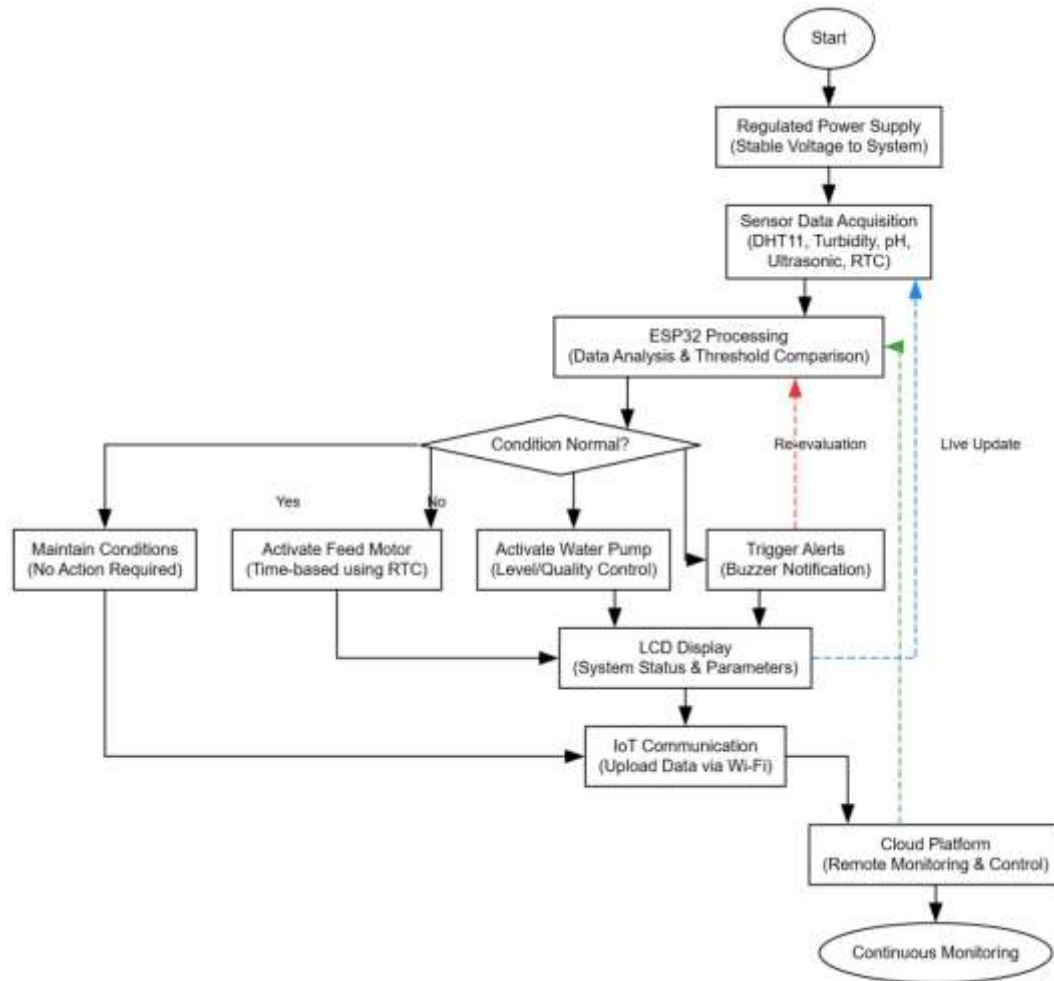


Figure 2. Proposed System Working Procedure.

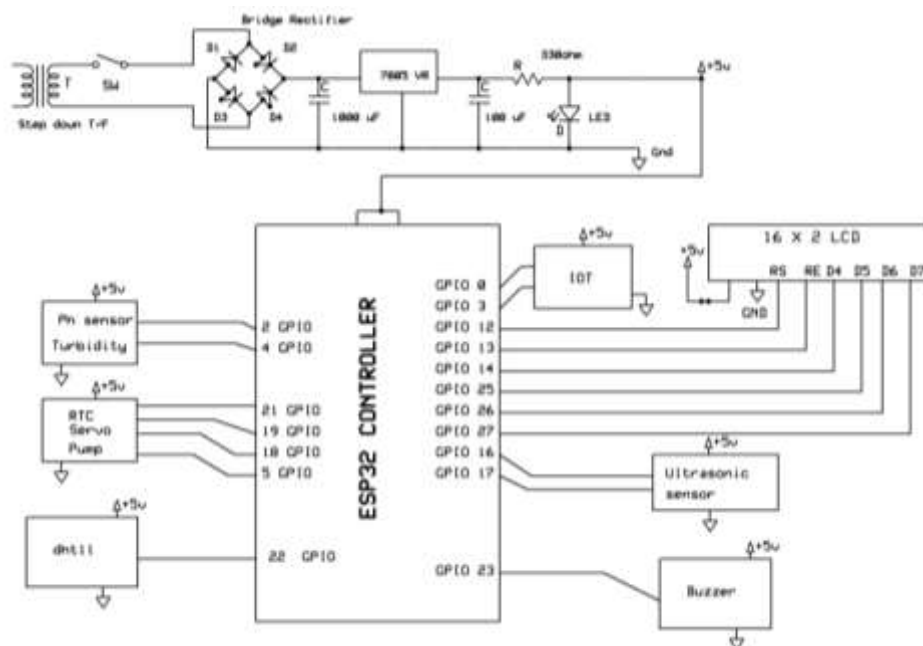


Figure 3. Schematic Diagram.

The ESP32 microcontroller serves as the central unit, interfacing with sensors such as a

pH sensor and turbidity sensor for water quality assessment, a DHT11 sensor for

temperature monitoring, and an ultrasonic sensor for water level detection. An RTC module enables time-based operations such as scheduled feeding, while a servo motor controls the feed dispensing mechanism and a water pump manages water circulation. The system includes a 16×2 LCD for displaying real-time data and a buzzer for alert notifications during abnormal conditions.

Additionally, IoT connectivity allows remote monitoring and control via cloud platforms. This integrated design ensures efficient fish farm management by maintaining optimal environmental conditions, automating feeding and water control, and reducing manual intervention.

4. Results and Discussion

Figure 4 shows the complete hardware implementation of the smart fish farming system developed using the ESP32 microcontroller. The system integrates sensors such as turbidity, temperature, humidity, and ultrasonic sensors along with a feed motor and water pump to automatically monitor and control the aquaculture environment.

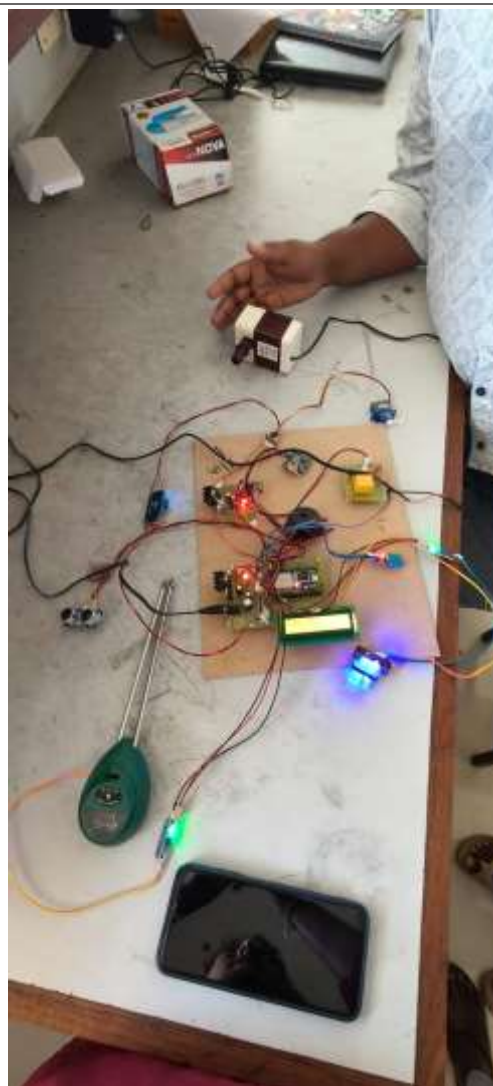


Figure 4. Hardware Prototype of IoT Smart Fish Farming System

S.No	pH	Turbidity	Temperature	Humidity	Status	Ultrasonic	Date
1	0	365	29.20	28.00	Pump-OFF	U:50	2026-02-09 14:38:12
2	0	416	29.30	29.00	Pump-ON	U:36	2026-02-09 14:36:11
3	0	418	29.20	28.00	Pump-ON	U:36	2026-02-09 14:33:28
4	0	418	29.20	28.00	Feeding-ON	U:36	2026-02-09 14:33:18
5	0	348	29.30	29.00	Pump-OFF	U:37	2026-02-09 14:31:59
6	0	348	29.30	29.00	Pump-ON	U:37	2026-02-09 14:31:48
7	0	348	29.30	29.00	Feeding-ON	U:37	2026-02-09 14:31:38
8	0	346	29.90	29.00	Pump-OFF	U:37	2026-02-09 14:29:09
9	0	346	29.90	29.00	Pump-ON	U:37	2026-02-09 14:28:59
10	0	354	30.00	27.00	Pump-OFF	U:37	2026-02-09 14:28:44
11	0	354	30.00	27.00	Pump-ON	U:37	2026-02-09 14:28:34
12	0	384	30.20	27.00	Pump-OFF	U:37	2026-02-09 14:28:19
13	0	384	30.20	27.00	Pump-ON	U:37	2026-02-09 14:28:09
14	0	384	30.20	27.00	Feeding-ON	U:37	2026-02-09 14:27:59

Figure 5. IoT Cloud Monitoring Interface for Fish Farming System.

Figure 5 illustrates the IoT web dashboard used for monitoring fish farming parameters

remotely. The interface displays real-time sensor data such as pH, turbidity, temperature,

humidity, water level (ultrasonic), and system status including pump and feeding operations with timestamps.

5. Conclusion

The proposed IoT Smart Fish Farming system offers an advanced and efficient solution for modern aquaculture by integrating real-time monitoring, automation, and intelligent control mechanisms. By utilizing the ESP32 microcontroller along with temperature, humidity, and turbidity sensors, the system ensures continuous assessment and maintenance of optimal water conditions essential for aquatic life. The inclusion of an RTC-based automated feeding system guarantees precise and timely feed distribution, reducing wastage and improving growth rates. Additionally, automated inlet and outlet pumps help maintain water quality, while IoT and Bluetooth connectivity enable both local and remote monitoring, data logging, and system control. This reduces dependency on manual intervention and enhances operational accuracy and efficiency. Finally, the system improves fish health, increases productivity, minimizes resource wastage, and supports sustainable aquaculture practices, making it a reliable and intelligent solution for next-generation fish farming systems.

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