

IOT Based Smart Aquaponics System

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ABSTRACT

The IoT-Based Smart Aquaponics System is an intelligent farming solution that combines aquaculture and hydroponics with IoT technology, automation, and image processing. The system uses an ESP32 microcontroller to monitor water quality parameters such as pH, turbidity, temperature, humidity, and water level. Sensor data is transmitted to Firebase for real-time monitoring and storage. Water pumps and automatic fish feeders are controlled through L298N motor drivers. Webcams continuously capture images of fish and plants, which are analysed using Python and OpenCV to identify unhealthy plants and dead fish. The system generates alerts, email notifications, and daily reports, reducing manual intervention and improving productivity. This smart system provides a sustainable, efficient, and scalable approach to modern aquaponics farming.

1. INTRODUCTION

Aquaponics is a sustainable farming technique that combines fish cultivation and plant growth in a single recirculating ecosystem. Fish waste provides nutrients for plants, while plants naturally filter water for the fish. Maintaining suitable water quality and environmental conditions is essential for system success. Traditional aquaponics systems require continuous monitoring and manual control. The proposed IoT-Based Smart Aquaponics System addresses these challenges by integrating sensors, cloud computing, image processing, and automation technologies. The system enables real-time monitoring, automated control, and intelligent decision-making, improving efficiency and reducing human effort.

[1] The manual explains aquaponics principles, nitrogen cycling, system design, water quality, fish–plant–bacteria interactions, management practices, pest and disease control, sustainable production, troubleshooting, and economic feasibility for small-scale food production.

[2] The technical paper presents aquaponics fundamentals, fish and vegetable cultivation, water chemistry, filtration systems, nutrient recycling, operational management, troubleshooting, environmental sustainability, and practical guidelines for small-scale farming.

[3] The publication explains fish physiology, endocrine regulation, growth, reproduction, environmental adaptation, metabolism, osmoregulation, stress responses, and hormonal control, highlighting physiological mechanisms influencing fish health, development, and aquaculture productivity.

[4] The review discusses IoT-based aquaponics automation, smart sensors, data monitoring, wireless communication, artificial intelligence, remote control, environmental management, system

optimization, sustainability, and improved fish and plant production efficiency,

[5] The study presents an economical IoT-based smart aquaponic system featuring real-time monitoring, automated control, sensor integration, wireless communication, improved resource efficiency, sustainable production, and reduced operational costs.

[6] The study develops an ESP32-based cloud monitoring system for aquaponics, enabling real-time sensing of abiotic factors, IoT connectivity, remote monitoring, data logging, environmental management, and improved operational efficiency.

[7] The paper presents an IoT-based aquaponics system for data acquisition and automated actuation, integrating sensors, controllers, realtime monitoring, environmental control, remote management, and improved system efficiency.

[8] The study proposes an IoT-based smart aquaponic system with realtime monitoring and automated control, integrating sensors, wireless communication, environmental management, remote access, and enhanced fish–plant production efficiency.

[9] The paper presents a modular IoT aquaponics monitoring system using edge computing, enabling real-time data processing, sensor integration, low-latency monitoring, efficient resource management, scalability, and improved system reliability.

[10] The study implements an IoT-based automated aquaponic system integrating sensors, microcontrollers, real-time monitoring, automated environmental control, wireless communication, resource optimization, and improved fish and plant cultivation efficiency.

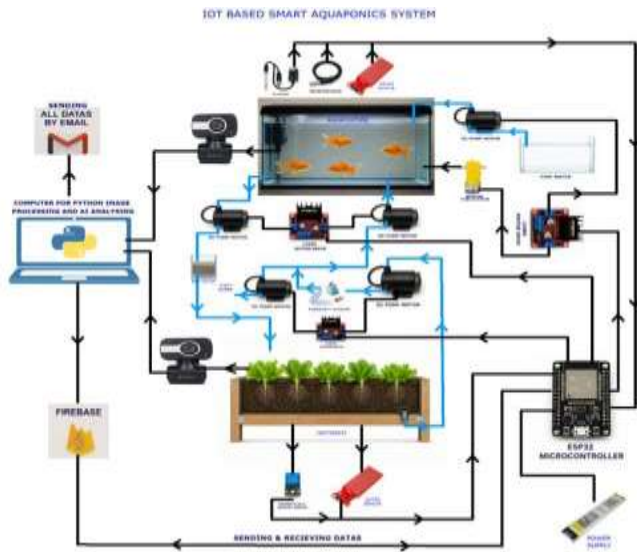
2. PROPOSED SYSTEM

The proposed system utilizes an ESP32 microcontroller as the central control unit. Multiple sensors continuously monitor water quality and environmental conditions. Sensor readings are transmitted to Firebase through Wi-Fi for remote monitoring. Water pumps circulate water between the fish tank and grow bed, while a motorized feeder supplies fish food automatically. Webcams capture images of fish and plants, and image processing algorithms identify unhealthy plants and dead fish. Whenever abnormal conditions are detected, email notifications are generated automatically. The system provides real-time monitoring, automated control, and intelligent analysis for efficient aquaponics management.

3. BLOCK DIAGRAM

The block diagram consists of the ESP32 microcontroller, sensor modules, webcams, Firebase cloud platform, motor drivers, water

pumps, fish feeder motor, and image processing unit. Sensors collect environmental data and send it to the ESP32. The ESP32 processes the information and uploads it to Firebase. The webcam images are analysed using Python and OpenCV. Based on sensor readings and image analysis results, the system controls pumps and feeders while generating alerts and reports into the gmail on particular time



4. CONTENTS

The sensors continuously monitor water quality and environmental conditions. The ESP32 collects the data and uploads it to Firebase. Water circulation pumps maintain nutrient flow between the fish tank and grow bed. The feeder motor provides food to fish at scheduled intervals. Webcams capture images of fish and plants, which are analysed using Python and OpenCV. When unhealthy plants, dead fish, abnormal pH levels, or high turbidity values are detected, alerts and email notifications are automatically generated. Daily reports are also created for system monitoring.

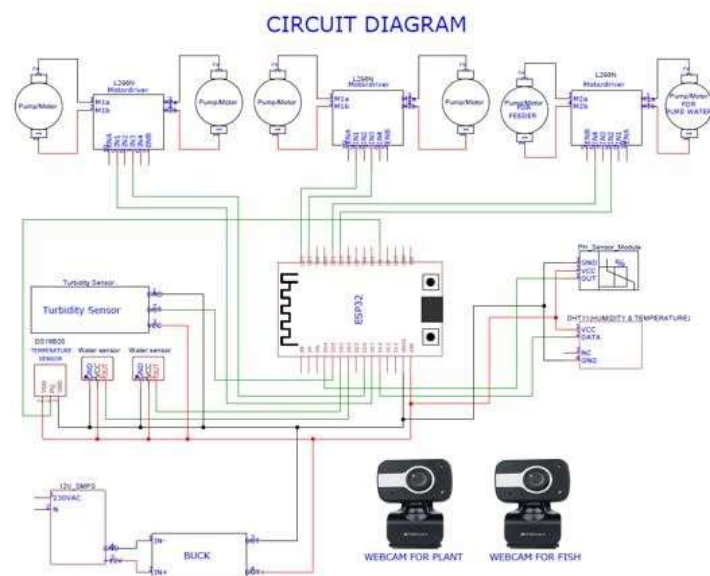
- ESP32 Microcontroller:** ESP32 is the main controller of the smart aquaponics system. It collects sensor data, processes information, controls pumps and feeders, connects to Wi-Fi, and uploads real-time data to Firebase cloud.
- pH Sensor:** The pH sensor measures the acidity or alkalinity of water. It helps maintain optimal water conditions for fish and plants by detecting pH fluctuations and triggering alerts when necessary.
- Turbidity Sensor:** The turbidity sensor measures water clarity by detecting suspended particles. High turbidity indicates poor water quality, prompting corrective actions and notifications to maintain a healthy aquaponics environment.
- Temperature and Humidity Sensor (DHT11):** The DHT11 sensor monitors ambient temperature and humidity levels around the aquaponics system. These measurements help maintain suitable environmental conditions for plant growth and overall system stability.
- Water Level Sensor:** The water level sensor continuously measures the amount of water in tanks. It prevents overflow or low-water conditions and ensures proper operation of pumps and fish habitats.
- Webcam Modules:** Webcam modules capture live images and videos of fish and plants. They enable image processing for detecting unhealthy plants, dead fish, and other abnormalities in real time.
- L298N Motor Drivers:** The L298N motor driver controls DC motors and pumps by receiving commands from the

ESP32. It provides sufficient current and voltage to operate connected devices efficiently.

- Water Pumps:** Water pumps circulate water between fish tanks and plant beds. They ensure nutrient distribution, oxygenation, and filtration, maintaining a balanced and healthy aquaponics ecosystem.
- Fish Feeder Motor:** The fish feeder motor automates feeding schedules by dispensing food at predetermined intervals. This ensures consistent feeding, reduces manual effort, and improves fish health management.
- Firestore Cloud Platform:** Firestore is a cloud-based platform used for storing sensor data, images, and system logs. It enables remote monitoring, real-time updates, and secure data synchronization.
- Python and OpenCV:** Python and OpenCV perform image processing and analysis on captured webcam images. They detect unhealthy plants, dead fish, and abnormal conditions, enabling intelligent monitoring and alerts.
- Email Notification System:** The email notification system sends instant alerts when abnormal conditions occur, such as pH imbalance, high turbidity, or low water levels, ensuring timely user intervention.

5. CIRCUIT DIAGRAM

The circuit consists of an ESP32 connected to pH, turbidity, temperature, humidity, and water level sensors. L298N motor drivers interface the ESP32 with DC pumps and feeder motors. A 12V SMPS and buck converter provide regulated power to all components. Webcam modules are connected to the computer for image acquisition and processing. The ESP32 communicates with Firebase through Wi-Fi for cloud monitoring and control.

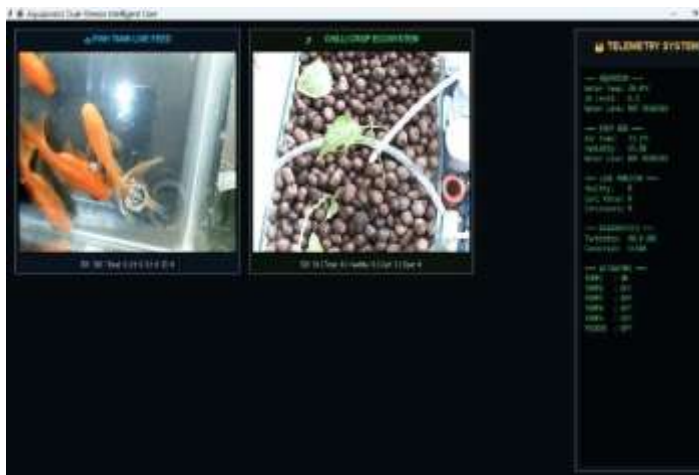


6. WORKING

The sensors continuously monitor water quality and environmental conditions. The ESP32 collects the data and uploads it to Firebase. Water circulation pumps maintain nutrient flow between the fish tank and grow bed. The feeder motor provides food to fish at scheduled intervals. Webcams capture images of fish and plants, which are analysed using Python and OpenCV. When unhealthy plants, dead fish, abnormal pH levels, or high turbidity values are detected, alerts and email notifications are automatically generated. Daily reports are also created for system monitoring.

7. IMPLEMENTATION AND TEST RESULT

The Smart Aquaponics System was implemented using an ESP32 microcontroller, pH sensor, turbidity sensor, DS18B20 temperature sensor, DHT11 sensor, water level sensor, webcam, pumps, and feeding motor. Sensor data is collected and transmitted to Firebase and displayed on the Tinker platform for real-time monitoring. The webcam captures images of fish and plants, which are analysed using Python-based image processing to detect unhealthy fish, dead fish, and unhealthy plants. The system automatically sends alert notifications for abnormal pH, turbidity, fish health, and plant health conditions. Daily reports containing all sensor readings and health status are also generated and sent to the user.



The system was tested under various conditions and successfully monitored water quality and environmental parameters. Real-time sensor data was accurately displayed on Firebase and Tinker. The image processing module successfully detected unhealthy fish, dead fish, and unhealthy plants from captured images. Alert messages were generated immediately when abnormal pH levels, turbidity spikes, or unhealthy conditions were detected. Daily reports were generated correctly, confirming the reliable performance of the system for automated aquaponics monitoring.

8. CHARACTERISTIC OUTPUT Table 1: Fish Tank Monitoring Data

Date	pH	Temperature (°C)
16-06-2026	6.3	30.5
17-06-2026	6.8	26.8
18-06-2026	6.5	27.0
19-06-2026	7.0	30.7
20-06-2026	6.8	28.4
21-06-2026	6.5	26.9
22-06-2026	6.1	28.1
23-06-2026	7.0	26.8
24-06-2026	6.9	30.6
25-06-2026	6.7	26.9

FISH TANK MONITORING

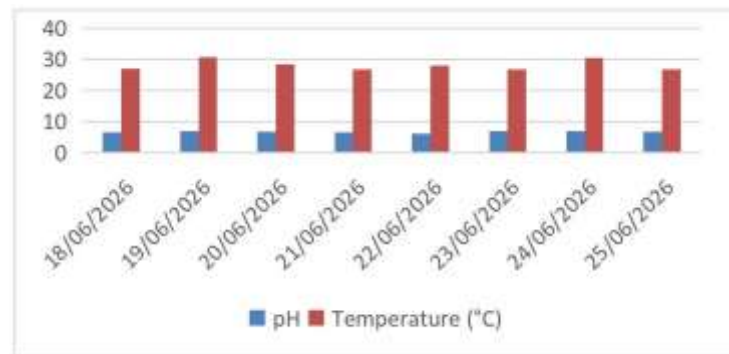
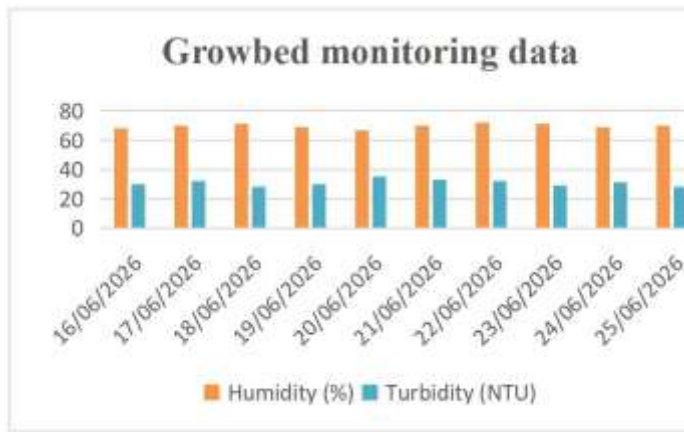


Table 2: Plant Bed Monitoring Data

Date	Humidity (%)	Turbidity (NTU)
16-06-2026	68	30.2
17-06-2026	70	32.1
18-06-2026	71	28.3
19-06-2026	69	30.0
20-06-2026	67	35.4
21-06-2026	70	33.2
22-06-2026	72	32.1
23-06-2026	71	29.3
24-06-2026	69	31.2
25-06-2026	70	28.1



9. ADVANTAGES

- Real-Time Monitoring of Water Quality:** Continuously tracks pH, turbidity, temperature, and water levels, ensuring healthy conditions for fish and plant growth.
- Automated Fish Feeding System:** Dispenses food automatically at scheduled times, ensuring regular feeding and reducing dependence on manual intervention.
- Reduced Human Intervention:** Automated monitoring and control functions minimize manual work, saving time and improving system management.
- Early Detection of Unhealthy Plants and Dead Fish:** Uses cameras and image analysis to identify unhealthy plants or dead fish before serious issues occur.
- Cloud-Based Remote Monitoring:** Users can view live sensor readings and system status from anywhere using internet connectivity.
- Improved Crop Yield and Fish Health:** Maintains ideal environmental conditions, promoting healthier fish, better plant growth, and increased productivity.
- Reduced Water Consumption:** Recirculates water within the system, minimizing wastage and maximizing resource utilization.
- Sustainable Farming Solution:** Combines aquaculture and hydroponics to create an environmentally friendly and resource-efficient farming method.
- Automatic Alert Generation:** Generates instant warnings when abnormal conditions occur, enabling quick corrective actions.
- Daily Performance Reporting:** Provides daily summaries of sensor data, system performance, and detected events for analysis.

9. APPLICATIONS

- Smart Agriculture:** Integrates sensors and automation technologies to improve farming efficiency, productivity, and resource management.
- Urban Farming Systems:** Enables food production in limited city spaces using compact and efficient aquaponics setups.
- Greenhouse Cultivation:** Maintains controlled environmental conditions for year-round cultivation of plants and fish.
- Educational and Research Institutions:** Provides practical learning and research opportunities in agriculture, IoT, and environmental sciences.

5. Commercial Aquaponics Farms: Supports large-scale production of fish and vegetables with automated monitoring and management.

6. Sustainable Food Production: Produces healthy food while minimizing water usage and environmental impact.

7. Environmental Monitoring Systems: Continuously monitors water quality and environmental conditions for ecosystem protection.

8. IoT-Based Agricultural Automation: Uses connected devices to automate farming operations and improve decision-making.

9. Home Gardening Systems: Allows households to grow fresh vegetables and raise fish in small spaces.

10. Organic Farming Applications: Supports chemical-free cultivation methods, promoting healthier crops and sustainable agricultural practices.

11. Fish Hatchery Management: Monitors water parameters and feeding schedules to improve fish survival and growth.

12. Hydroponic Integration Systems: Combines aquaponics with hydroponics for efficient nutrient utilization and crop production.

13. Remote Farm Management: Enables farmers to monitor and control systems remotely through internet connectivity.

14. Water Conservation Projects: Reduces water wastage through recirculation and efficient resource management techniques.

15. Climate-Smart Agriculture: Adapts farming practices to changing environmental conditions using intelligent monitoring technologies.

10. FUTURE SCOPE

- AI & Computer Vision:** Integrating cameras and Machine Learning to automatically detect plant diseases, nutrient deficiencies, and abnormal fish behaviour.
- Renewable Energy Autonomy:** Transitioning to an off-grid system powered entirely by solar panels and backup batteries to eliminate the risk of power outages.
- Edge Computing:** Enabling the local microcontrollers to make critical decisions independently so the system keeps running smoothly even if the Wi-Fi drops.
- Automated Chemical Balancing:** Adding precise automated pumps that can automatically inject natural pH adjusters or organic nutrients when sensors detect an imbalance.
- Commercial Scaling (LoRa Mesh):** Using long-range wireless networks (like LoRa) to connect multiple tanks and grow-beds together, turning a small project into a large-scale commercial farm.

11. CONCLUSION

The IoT-Based Smart Aquaponics System provides an efficient and intelligent solution for sustainable farming. By integrating IoT, image processing, cloud computing, and automation technologies, the system ensures continuous monitoring and control of aquaponics

environments. The automated monitoring, alert generation, and image-based health analysis improve productivity while reducing manual effort. The proposed system contributes to modern precision agriculture and supports environmentally friendly food production.

12. REFERENCE

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