

Smart Aquaponic System (SAS): An IoT-Based Approach for Sustainable Farming

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Abstract:

Aquaponic farming integrates aquaculture and hydroponics sustainability in food production. Aquaponics combines aquaculture and hydroponics for creating an environmentally friendly and sustainable way of food production. Yet, the current solutions are not efficient as they have low level of automation and lack of real-time monitoring. In this paper, a Smart Aquaponic System (SAS) with Internet of Things(IoT) and automated actuators is proposed for continuous monitoring of the water quality (pH, temperature, turbidity, & humidity) and light intensity. The system also exploits cloud connection for remote read out and control. The experimental deployment proved that productivity increased, manual intervention diminished and sustainability increased. The SAS offers a scalable and intelligent solution to address global food security challenges.

I. INTRODUCTION

Aquaponics integrate aquaculture with soilless farming, forming a collaborative ecosystem where the fish waste feeds the plants, and the plants purifier the water for the fish. Although supportable, becomes the steady when the pH, O₂ and T were observed on a constant basis. Manual watering can be unhurried and inefficient; rescheduling plant growing, contributing to fish die-off, and progressive time. In order to address these issues, a Smart Aquaponic System (SAS) including the IoT-based monitoring and automation that ensures the best working environments is recommended in this slog.

Objectives of this work include:

The system concentrations on **systematizing the observing and regulator of ecological parameters**, thereby dropping manual involvement and diminishing the chances of human

mistake. By **leveraging predictive analytics**, it enables positive system managing to continue optimal conditions. Overall, the approach cares **maintainable and mountable aquaponic agrobusiness**, ensuring proficiency, consistency, and long-standing productivity.

II. RELATED WORK

- A. The study titled "*Optimizing Green Internet of Things Architecture in a Multi-loop Aquaponics System*" by R. Mahkeswaran introduces a Green IoT (G-IoT) framework designed to enhance energy efficiency and scalability in traditional aquaponics systems. It integrates low-power sensors, energy harvesting, and lightweight communication protocols to monitor water quality, nutrient flow, temperature, and pH levels. By incorporating edge computing, the system reduces latency and enables faster decision-making. Additionally, machine learning

models are applied to predict anomalies and optimize energy usage. Field trials demonstrated a 20% reduction in energy consumption and an 18% increase in crop yield, proving the system's potential as a sustainable and scalable solution for smart aquaponics in various climates.

- B. The study titled *"Photovoltaic-powered Smart Aquaponic System: Integrating IoT and AI for Sustainable Food Production and Fish Health Management"* by Heba Mohamed Abd El-Atty presents a solar-powered smart aquaponic system that combines renewable energy, IoT, and AI to promote sustainable agriculture. Designed for rural and off-grid areas, the system utilizes photovoltaic panels to minimize carbon emissions and ensure energy self-sufficiency. It employs sensors to monitor critical parameters such as ammonia levels, water temperature, pH, and dissolved oxygen, with AI algorithms managing data and enabling real-time adjustments for optimal plant and fish health. Machine learning models offer predictive insights, while automated actuators control feeding, water circulation, and nutrient dosing. The system achieved a 23% increase in crop yield, a 20% reduction in fish mortality, and lower operational costs, demonstrating its effectiveness as an eco-friendly and efficient solution for modern aquaponics.
- C. The study titled *"IoT-based Prediction Model for Aquaponic Fish Pond Water Quality Using Multiscale Feature Fusion with Convolutional Autoencoder and GRU Networks"* by Suma Christal Mary Sundararajan introduces an IoT-driven predictive model that enhances water quality monitoring in aquaponic systems through advanced deep learning techniques. The model leverages convolutional autoencoders (CAE) to extract deep features from sensor data and GRU networks to capture temporal patterns, enabling accurate multiscale predictions of key parameters such as pH,

dissolved oxygen, and ammonia levels. By integrating multiple time scales, the system delivers context-aware and robust forecasting. Experimental results showed a 92% prediction accuracy, outperforming traditional models like ARIMA. The system also reduced fish mortality by 15% and improved nutrient distribution for plant growth, demonstrating the potential of combining IoT and deep learning for autonomous and sustainable aquaponic management.

- D. The study titled *"Aquaponic Farming with Advanced Decision Support System: Practical Implementation and Evaluation"* by Eleftheria Maria Pechlivani introduces an advanced Decision Support System (DSS) designed to streamline aquaponic farming by reducing reliance on manual data interpretation and mitigating operational inefficiencies. The system integrates real-time sensor data with machine learning algorithms to assess water quality, nutrient deficiencies, and plant health. It features a user-friendly dashboard that provides actionable insights and automated alerts during critical events. Field evaluations demonstrated a 22% boost in operational efficiency and an 18% reduction in costs, while assessments confirmed strong performance in terms of accuracy, response time, and scalability. This DSS proves to be an effective tool for sustainable, data-driven aquaponic management.

III. EXISTING SYSTEM

Outdated aquaponic systems mostly depend on manual observing and regulator, making them time-overriding and motionless to human mistake. While some systems include elementary sensors for investigation, they often deficiency automated response mechanisms and have not at all predictive intelligence. As a outcome, plants and fish involvement stress due to behind interventions, and resource consumption remains inefficient, instigating wastage and higher expenses.

Additionally, these systems agonize from deprived scalability and flexibility, which confines their efficiency in various environments and big-scale applications.

A. Drawback

Existing aquaponic systems agonize from substantial reliance on manual involvement, which restrictions effectiveness and exactness. The absence of progressive automation limits real-time regulator and timely responses. Additionally, these arrangements demonstrate poor scalability for profitable applications and work without extrapolative analytics for practical management. As a result, resource consumption remains inefficient, reducing both sustainability and efficiency.

IV. PROPOSED WORK:

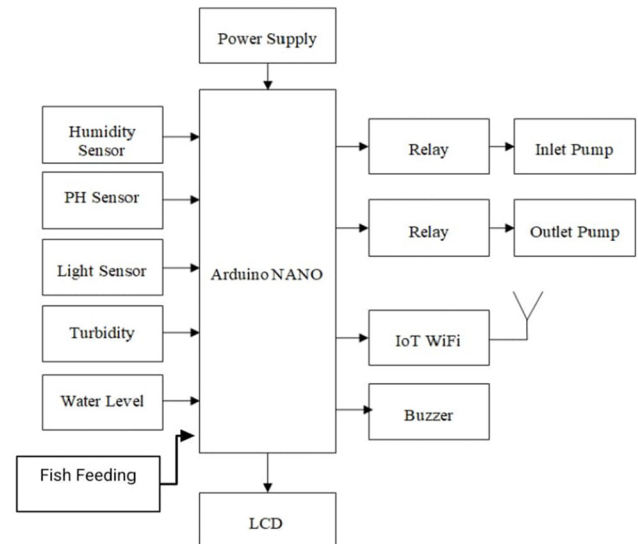
The Smart Aquaponic System (SAS) integrates IoT-based sensors and actuators to enable real-time monitoring and control of the aquaponic environment. A range of sensors measure water pH, turbidity, humidity, temperature, and light, with data processed by the Arduino Nano controller for decision-making. Connectivity is achieved through the ESP8266 module, which transmits data to the ThingSpeak cloud for remote access. Actuators such as pumps, aerators, and lighting devices are automated based on sensor inputs, while notifications are delivered via LCD display and buzzer for on-site alerts, and cloud-based alerts for remote users. The SAS ensures real-time anomaly detection, proactive adjustments, and remote accessibility, thereby improving reliability, reducing labor costs, and enhancing system scalability.

A. Advantages :

The proposed system enables continuous automated monitoring and adjustment of key environmental parameters, ensuring stable operation without constant human supervision. By optimizing resource utilization, it achieves reduced water and nutrient wastage, supporting sustainable farming practices. The design is scalable for both small-scale

and commercial applications, making it adaptable across diverse contexts. Overall, the system promotes improved plant growth and fish health, leading to higher productivity and efficiency in aquaponic farming.

V. BLOCK DIAGRAM



VI. MODULE DESCRIPTION

- A. Power Supply Module:**
This module provides regulated 12V and 5V power to the entire system, including the Arduino Nano, ESP8266 Wi-Fi module, sensors, relays, LCD display, and buzzer. It initiates the power-on self-test, where the Arduino checks sensor presence, reads stored configurations from EEPROM, and displays boot status on the LCD, ensuring that the system is fully functional before entering normal operation.
- B. Sensor Module:**
The system uses a set of sensors to monitor key environmental parameters critical for aquaponics. These include a pH sensor, turbidity sensor, water level sensor, DS18B20 temperature sensor, DHT11/DHT22 humidity sensor, and an LDR or photodiode-based light sensor. These sensors capture real-time data on water and air conditions, which are essential for maintaining optimal plant and fish health.
- C. Microcontroller & Processing Module:**
At the core of the system, the Arduino Nano microcontroller manages sensor data

acquisition, filtering using Exponentially Weighted Moving Average (EWMA), and unit conversion. It applies threshold-based decision logic to determine appropriate control actions, manages EEPROM storage, handles local display updates, and ensures system stability through watchdog timers and error handling routines.

D. **Connectivity** **Module:**

The ESP8266 Wi-Fi module enables network connectivity by connecting the system to a pre-configured Wi-Fi network. It uploads processed sensor data to the ThingSpeak cloud platform via HTTP or MQTT protocols. If the network is unavailable, it operates in offline mode and retries connection attempts periodically, ensuring continuous operation.

E. **Actuation** **Module:**

This module controls mechanical components such as the inlet pump, outlet pump, and optional grow light via relays. Based on sensor readings and decision logic, it automates water circulation and lighting. A buzzer is also included to sound local alarms during critical conditions, such as extreme pH or water level deviations.

F. **Display & Notification** **Module:**

The local user interface is handled by a 16×2 LCD display and a buzzer. The LCD cycles between two display pages showing sensor values such as pH, temperature, turbidity, humidity, light intensity, and water level. When an alert condition arises, it displays scrolling warning messages, while the buzzer provides immediate audible feedback for on-site users.

G. **Cloud Integration** **Module:**

ThingSpeak serves as the cloud backend for remote monitoring and alerting. Each sensor parameter is mapped to specific ThingSpeak fields (F1 to F8), and the system uploads data periodically. When abnormal readings persist, it tags the upload with a status code and triggers email or SMS notifications via pre-configured rules.

H. **Fault Detection & Safety** **Module:**

To ensure reliability, this module handles anomalies such as sensor malfunctions or

stuck readings. In such cases, the system ignores faulty data, enters a safe state by turning off all pumps, and alerts the user. A watchdog timer resets the microcontroller in the event of a software freeze, enhancing fault tolerance.

I. **Data Logging & Review** **Module:**

All time-stamped sensor data is stored on the cloud for historical analysis. Weekly CSV exports allow for detailed review, trend analysis, and threshold optimization. This module enables long-term data tracking, which supports informed decision-making and continuous system improvement.

VII. CONCLUSION

The Smart Aquaponic System (SAS) properly embeds the IoT in the PA and to automate the monitoring and the control of aquaponic systems. It enhances sustainability effectiveness, efficiency, productivity by decreasing dependency on men power. The initiative showcases the power of IoT in agriculture to safeguard global food security.

VIII. FUTURE WORK

Future enhancements for the Smart Aquaponic System (SAS) aim to further improve efficiency and sustainability. The system can be extended with **machine learning algorithms** for predictive analytics and anomaly detection, enabling more proactive management. **Solar-powered energy solutions** will support off-grid farming and reduce dependence on conventional power sources. A dedicated **mobile application** can provide user-friendly monitoring and remote control. The integration of **advanced sensors** such as dissolved oxygen and nutrient concentration will enhance accuracy in environmental monitoring. Finally, **cloud-based analytics** can be expanded to support long-term optimization, performance evaluation, and trend prediction, ensuring scalability for future smart agriculture applications.

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