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Media-Based Aquaponics Using IOT Components for Smart Agriculture

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Abstract
Ensuring optimal water quality is essential for efficient aquaculture and aquaponics management. This paper presents an IoT-based intelligent monitoring system that integrates Edge Computing (Raspberry Pi 4 Model B) and Fog Computing (ESP32) for real-time water quality analysis and control. The system utilizes pH, TDS, temperature, and turbidity sensors to monitor water conditions, while air pumps, water pumps, solenoid valves, servo motors, buzzers, and thermoelectric Peltier systems regulate environmental factors. The Edge Computing unit preprocesses data and applies lightweight machine learning models, while the Fog Computing layer transmits refined data to the cloud for remote monitoring and analytics. The proposed solution enhances water management efficiency, reduces manual intervention, and ensures optimal aquatic conditions for sustainable fish farming and plant growth.
Keywords: *Aquaponics; Automated Control; Edge Computing, Fog Computing; IoT; Real-time Monitoring; Sensor Integration; Smart Aquaculture; Water Quality Monitoring.*

1. Introduction
Aquaponics is an environmentally friendly agricultural system that integrates aquaculture (fish farming) and hydroponics (soilless cultivation of plants) in a closed system. Plants are fed fish waste, and plants purify and recycle water for the fish in aquaponics. This kind of symbiotic association between fish and plants can contribute to increased resource efficiency and sustainability. Traditional aquaponics systems, however, are likely to face issues owing to inconsistent monitoring, environmental control, and handling of resources. The integration of Internet of Things (IoT) technologies into aquaponics systems provides tremendous advantages in the form of real-time water quality monitoring and automatic control of environmental parameters. Farmers can continuously monitor such vital water quality parameters as pH, temperature, turbidity, and TDS (total dissolved solids) with the help of IoT and implement corrective actions on time to maintain optimal conditions for aquatic organisms and plants. In addition, predictive analytics powered by machine learning can be applied to predict water quality anomalies and enable automated intervention against system failure. This paper proposes an IoT-enabled intelligent aquaponics system that utilizes sensors and actuators to automatically monitor and control the water quality. Our interest lies in a hybrid system that integrates hardware components like Raspberry Pi, ESP32, and sensors, with machine learning algorithms for anomaly forecasting and system performance optimization.

2. Related Work
Several IoT-based aquaponic systems have been proposed over the last couple of years. These intend to maximize efficiency, reduce manual effort, and optimize sustainability. For instance, Kasyap et al. [1] developed an aquaponic system based on Arduino and IoT for monitoring aquatic quality and auto-irrigation. The authors have incorporated pH level,

temperature, and turbidity sensors so that fish and plants are properly well-fed. Another system by Silva et al. [2] combined machine learning algorithms with IoT sensors to predict water quality and optimize energy usage in aquaponics. Nevertheless, existing systems mostly offer support for monitoring or basic automation without embracing advanced predictive models for anomaly detection and resource optimization. These limitations are addressed in this paper by an aquaponics predictive modeling system using machine learning, with improved predictability and auto-intervention capabilities for water quality management.

3. Machine Learning Models

Machine learning algorithms are employed to predict water quality change and drive auto-corrective actions. Various models are utilized by the system for this:

M5 Model Tree: The M5 Model Tree is a regression-based decision tree that generates forecast models using decision trees and linear regression. It has good support for time series forecasting and hence suitable for forecasting changes in water quality from previous values.

Random Forest: Random Forest is an algorithm that aggregates predictions of many decision trees. It is famous for being robust and capable of reducing overfitting, a good model to use for predicting water quality.

Gradient Boosting: Gradient Boosting is yet another ensemble technique that builds a series of models sequentially, which tries to predict the errors made by the preceding model. Gradient Boosting has been found to perform well on regression tasks and is used here to forecast the water quality of this system.

Artificial Neural Networks (ANN): ANNs consist of layers of connected neurons that are capable of learning subtle patterns between inputs and outputs. In this case, the system utilizes ANNs for simulating the sensor inputs and water quality metrics relationship in order to achieve strong predictive capability.

Model Performance: The Random Forest and M5 Model Tree models were more accurate with both models having low MAE and RMSE values. The Gradient Boosting model provided competitive results, but the ANN model required further tuning to provide optimal performance.

4. Algorithm

Input: Real-time sensor data (Temperature, TDS, Turbidity, pH)

Output: Predicted water quality status and necessary system adjustments

- Step 1: Data Acquisition
- Collect sensor readings from temperature, TDS, turbidity, and pH sensors.
- Store readings in cloud storage for further processing.
- Step 2: Data Preprocessing
- Normalize sensor readings to eliminate noise and outliers.
- Apply data smoothing techniques to handle fluctuations.
- Step 3: Feature Extraction 10: Identify key features impacting water quality.
- Extract statistical properties from time-series data.
- Step 4: Model Selection and Training
- Train multiple machine learning models (M5 Model Tree, Random Forest, Gradient Boosting, ANN). 14: Evaluate model performance using metrics such as MAE, RMSE, and R-Squared.
- Step 5: Prediction and Decision Making
- Use the best-performing model for real-time prediction.
- If abnormal water quality is detected, trigger corrective actions.
- Step 6: Automated System Adjustments
- Activate actuators (water pump, air pump, thermistor) based on predicted insights.
- Send real-time alerts to users via a mobile application.
- End Algorithm

Conclusion

This paper introduced an IoT-based aquaponics system incorporating sensors, actuators, and machine learning algorithms for real-time water quality monitoring and control. The system showed improved predictive power, allowing early detection of anomalies and automated intervention, which

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leads to more sustainable and efficient aquaponics operations. Future endeavors will emphasize the extension of the sensor network, improving predictive models, and further system optimization for wide-scale application.

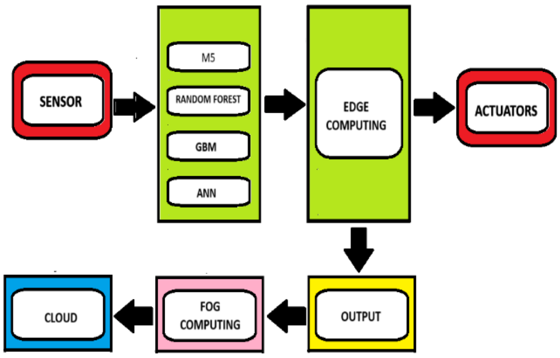

Figure 1 System Diagram

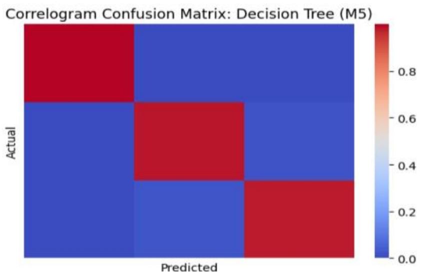

Figure 2 Confusion Matrix for M5

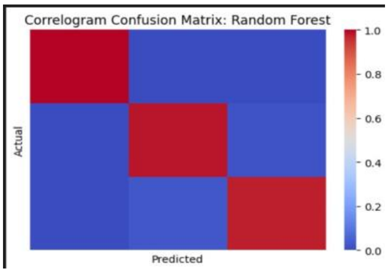

Figure 3 Confusion Matrix for Random Forest

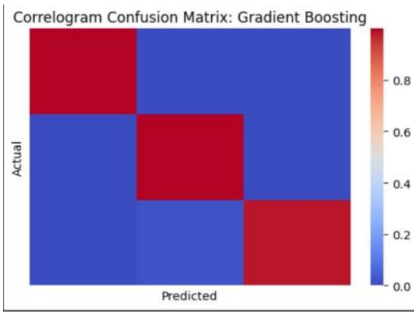

Figure 4 Confusion Matrix for Gradient Boosting

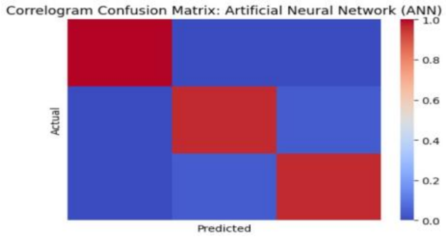

Figure 5 Confusion Matrix for ANN

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