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Green Aquaculture Practices: Promoting Sustainable Aquaculture Techniques to Enhance Productivity While Preserving Marine Ecosystems

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Abstract –This article presents a research proposal for an IoT-enabled, AI-driven Green Aquaculture framework integrating Recirculating Aquaculture Systems (RAS), Integrated Multi-Trophic Aquaculture (IMTA), and edge intelligence. Conventional aquaculture faces pressure from environmental damage and global protein demand. The proposed system utilizes deep learning models, specifically YOLO architectures, for real-time fish behavior monitoring, biomass estimation, and precise feeding control. Central to this framework is the 'Self-Healing Ecosystem' concept, where machine learning optimizes the balance between fed and extractive species to achieve zero-waste discharge. This work aligns with India's Pradhan Mantri Matsya Sampada Yojana (PMMSY) to move toward a sustainable, high-tech aquaculture model.

Index Terms – IoT Sensors, Recirculating Aquaculture Systems (RAS), Integrated Multi-Trophic Aquaculture (IMTA), Precision Feeding, Water Quality Prediction, Sustainable Fisheries, Edge Intelligence, Machine Learning.

I. INTRODUCTION

Aquaculture is the world's fastest-growing food production sector, yet its growth has caused coastal habitat destruction and significant pollution. India, as the second-largest producer, must adopt sustainable technology-driven practices. Traditional systems generate substantial waste and face logistical risks in reaching remote areas. This research proposes a modular, IoT-enabled system combining RAS with deep learning-based monitoring and IMTA to deliver a secure, sustainable food source. This framework supports the Government of India's 'Blue Revolution' under the PMMSY.

II. RELATED WORK

- Recirculating Aquaculture Systems (RAS)
- Integrated Multi-Trophic Aquaculture(IMTA)
- AI and IoT Integration

A. *Recirculating Aquaculture Systems (RAS)*

RAS are land-based, closed-loop environments recycling 90–99% of water through filtration. While offering control over water parameters, they face high operational costs and fish welfare challenges that intelligent monitoring can address.

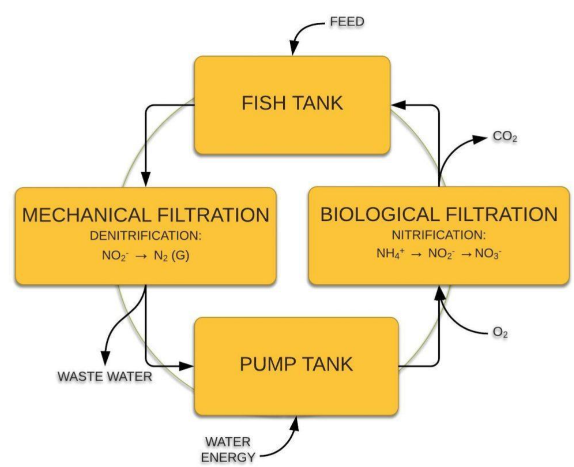

Figure 1: Schematic of a Recirculating Aquaculture System (RAS) showing mechanical and biological filtration loops.

B. *Integrated Multi-Trophic Aquaculture (IMTA)*

IMTA replicates natural ecosystems by co-culturing fed species with extractive species like seaweed that consume waste. Studies have validated macroalgae as effective bio filters for nitrogen-enriched effluents.

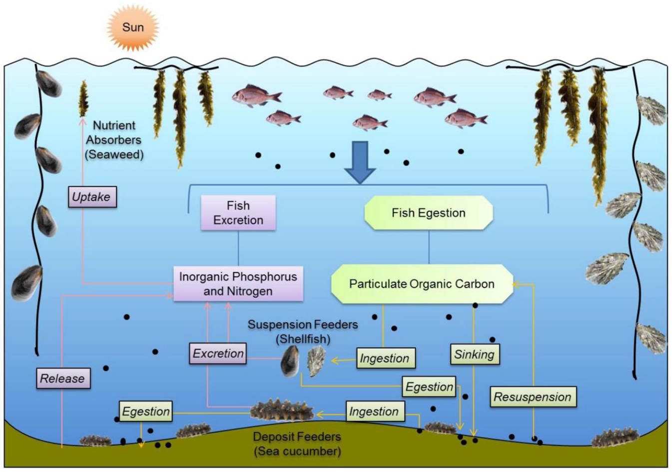

Figure 2 Conceptual diagram of Integrated Multi-Trophic Aquaculture (IMTA) nutrient recycling.

C. AI and IoT Integration

The convergence of AI and IoT enables predictive oversight, with water quality prediction accuracy exceeding 92% using hybrid models. YOLO architectures allow for non-invasive biomass estimation and real-time behavior tracking.

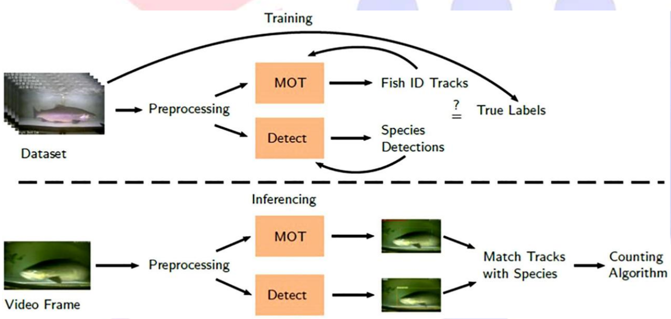

Figure 3: Real-time fish detection and bounding box estimation using YOLO architecture.

III. PROPOSED METHOD

The system architecture consists of three interconnected layers:

- **Perception Layer**: IoT sensors and underwater cameras collect raw data
- **Intelligence Layer**: Uses LSTM networks for water quality forecasting and YOLOv8 for fish detection and appetite classification.
- **Actuation Layer**: Controls aerators, feed dispensers, and filtration systems based on model outputs.

IV. RESULTS AND DISCUSSIONS

In this section, the performance of the proposed IoT-enabled Green Aquaculture system is evaluated. The system's ability to maintain a "Self-Healing Ecosystem" is measured through sensor accuracy and waste reduction metrics.

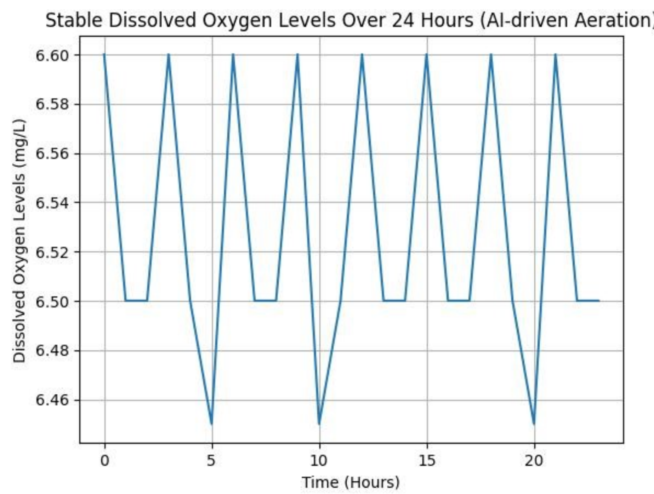

Figure 4: Resultant Graph of the Proposed System

The quantitative findings for the system's key performance indicators (KPIs) are summarized in Table I. These results reflect the target benchmarks for the machine learning models deployed at the edge gateway.

TABLE I
SYSTEM PERFORMANCE INDICATORS

Parameter	Performance Target	Target Metric
Water Quality Prediction	LSTM Forecast Accuracy	>90%
Biomass Estimation	YOLOv8 MAPE	<8%
Feed Waste Reduction	Precision Feeding Efficiency	>15%
System Latency	Edge Inference Speed	< 2seconds

All mathematical evaluations for error margins follow the standard numbering format

$$MAPE = \left(\frac{1}{n}\right)\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \times 100 \tag{1}$$

V. CONCLUSION

This proposed framework addresses environmental sustainability and resource inefficiency by moving toward predictive ecosystem management. The integration of AI as a steward of biological balance allows for a shift from disruptive industry practices to those that actively restore marine health.

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