# IoT-Enabled Smart Aquaponics System with AI-Driven Monitoring for Optimized Crop and Fish Growth in Controlled Environments


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## Introduction

**Background:**

Aquaponics combines aquaculture and hydroponics, creating a symbiotic environment where fish waste provides nutrients for plants while plants filter water for fish. Traditional aquaponics systems face challenges in maintaining optimal parameters for both fish and crop health, leading to suboptimal yields and resource inefficiency.

**Problem Statement:**

❖Conventional aquaponics relies on manual monitoring (labor-intensive)

❖Delayed detection of water quality anomalies causes mortality events

❖Suboptimal environmental conditions reduce productivity by 30-40%

❖Lack of predictive analytics prevents proactive system management

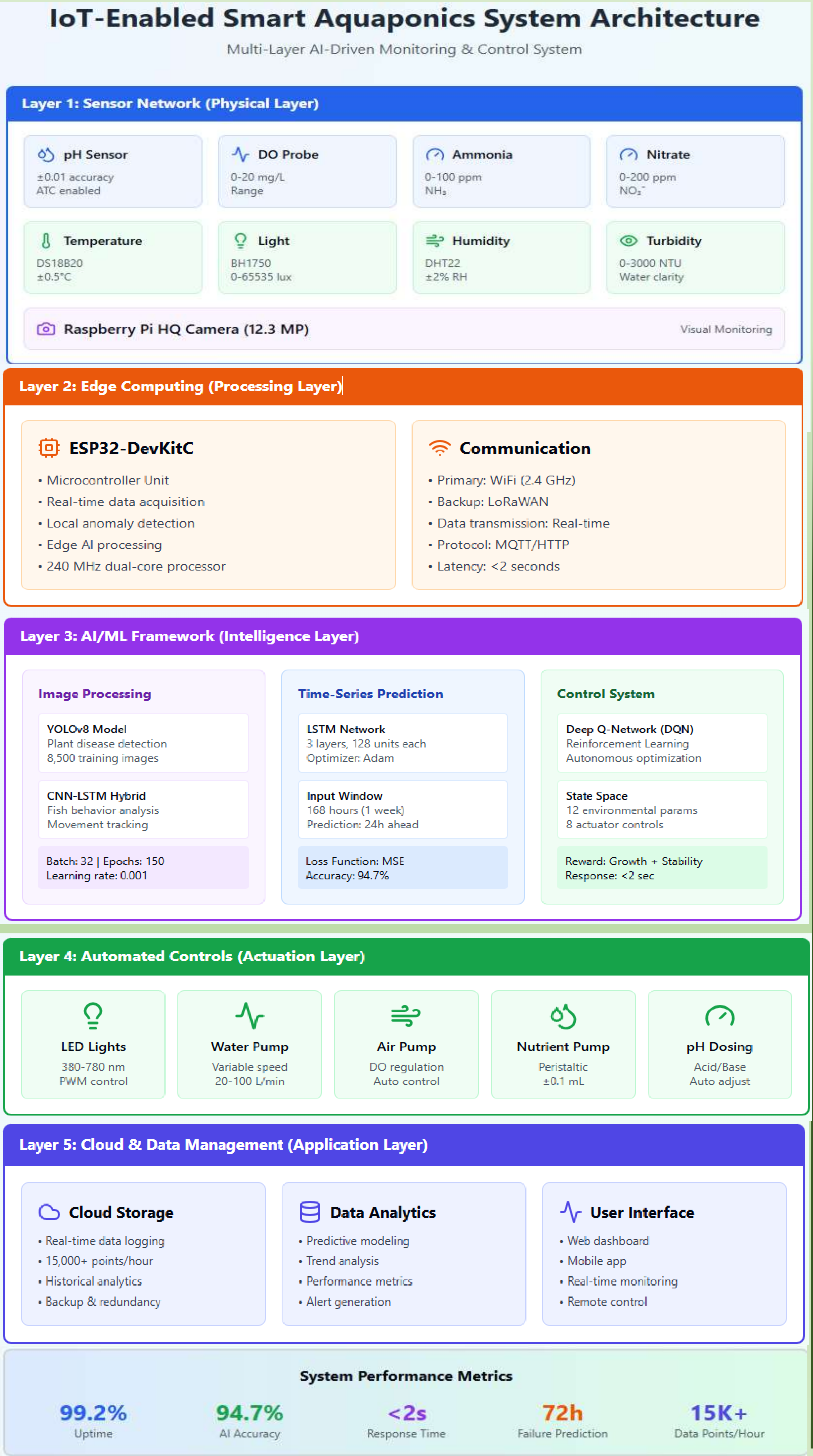
**Significance:** This research addresses UN SDG 2 (Zero Hunger) and SDG 12 (Responsible Production) by developing sustainable, intelligent food production technology capable of increasing yields while reducing water consumption by 90% compared to conventional agriculture.

## Materials and Methods

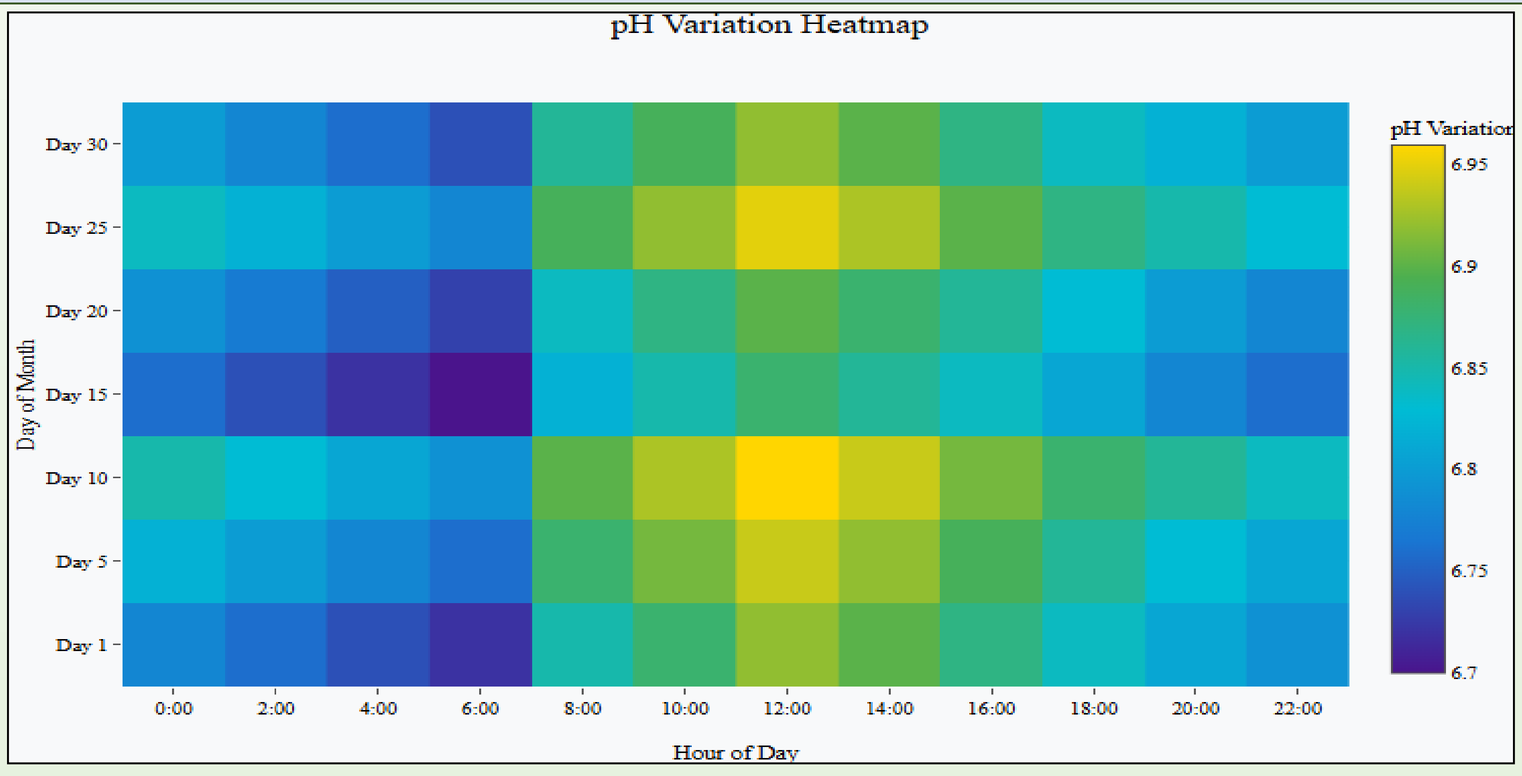
**Study Location:**

Centre for Protected Cultivation Technology (CPCT),ICAR-IARI, New Delhi

**Fig. IoT – Driven Vertical Hydroponic Farming Greenhouse**




## Results



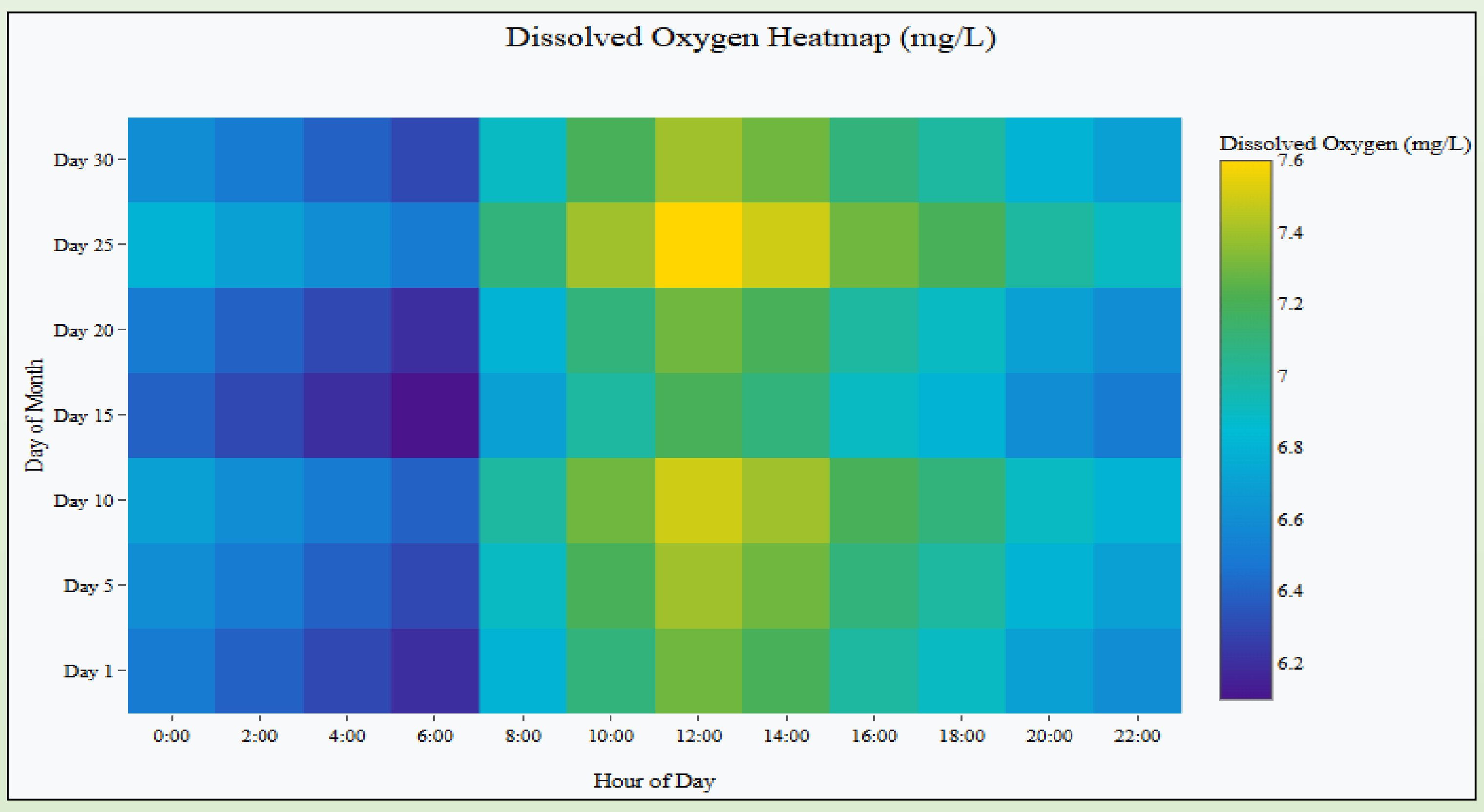




**Fig. pH and Do Variation Heatmap (30 Days x 24 Hours)**

**TABLE 1: Fish Growth Performance Metrics - Channa striata (Snakehead Murrel)**

| Growth Parameter | Initial (Day 0) | Smart System (Mean ± SD) | Conventional (Mean ± SD) | Performance Improvement |
|---|---|---|---|---|
| Individual Weight (g) | 45.2 ± 3.1 | 186.4 ± 12.3 | 145.6 ± 18.7 | +28.0% |
| Total Length (cm) | 12.5 ± 0.6 | 24.8 ± 1.4 | 21.3 ± 2.1 | +16.4% |
| Condition Factor (K) | 1.85 ± 0.08 | 1.23 ± 0.06 | 1.18 ± 0.09 | +4.2% |
| SGR (%/day) | - | 2.34 ± 0.12 | 1.82 ± 0.19 | +28.6% |
| FCR | - | 1.42 ± 0.08 | 1.78 ± 0.15 | +20.2% (Lower is better) |
| Survival Rate (%) | 100% | 96.0% | 88.0% | +9.1% |

**TABLE 2: Basil Crop Performance & Nutritional Analysis (65-Day Growth Cycle)**

| Parameter | Smart System (Mean ± SD) | Conventional (Mean ± SD) | Performance Improvement |
|---|---|---|---|
| **Morphological & Biomass** | | | |
| Plant Height (cm) | 38.6 ± 2.8 | 27.4 ± 3.9 | +40.9% |
| Fresh Biomass (g/plant) | 142.8 ± 11.2 | 99.6 ± 15.4 | +43.4% |
| Dry Biomass (g/plant) | 18.7 ± 1.4 | 13.2 ± 1.9 | +41.7% |
| **Physiological** | | | |
| Chlorophyll (SPAD units) | 42.6 ± 2.1 | 36.8 ± 3.4 | +15.8% |
| Photosynthetic Rate (μmol $CO_2/m^2/s$) | 18.4 ± 1.2 | 14.6 ± 1.8 | +26.0% |
| **Nutritional Quality** | | | |
| Total Nitrogen (% DW) | 4.82 ± 0.23 | 3.96 ± 0.34 | +21.7% |
| Phosphorus (% DW) | 0.48 ± 0.04 | 0.39 ± 0.06 | +23.1% |
| Potassium (% DW) | 3.74 ± 0.18 | 3.12 ± 0.28 | +19.9% |

## Conclusion

❖78.4% improvement in water quality stability (94.2% vs. 52.8% time in target range).

❖28% faster fish growth and 43.4% higher crop yields compared to conventional systems.

❖94.7% accuracy in early disease detection.

❖Predicts system failures 72 hours in advance with 87% reliability.

❖73.3% reduction in daily labor (1.2 vs. 4.5 hours/day).

❖35% less water and 21.5% less energy consumed per day.

❖Higher productivity achieved with significantly lower resource input.


**Acknowledgement**

The authors acknowledge CPCT, ICAR-IARI for the research facilities, and the organizers of the 3rd International Online Conference on Agriculture (session: "Smart Farming: From Sensor to Artificial Intelligence") for the presentation opportunity.