Smart Water Monitoring and Management System for Aquatic Environments

Project report in partial fulfilment of the requirement for the award of the degree of

Bachelor of Technology

In

Computer Science and Engineering (IOT, CS, BT)

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CERTIFICATE

This is to certify that the project titled **Smart Water Monitoring and Management System for Aquatic Environments** submitted by **Anup Dutta (Enrollment No. 12022002029086), Debanjan Karmakar (Enrollment No. 12022002029097), Kiran Das (Enrollment No. 12022002029104), Muskan Parvin (Enrollment No. 12022002029105), Poulami Sinha (Enrollment No. 12022002029108), Pranati Mondal (Enrollment No. 12022002029061), Sarmistha Pal (Enrollment No. 12022002029131), Soumyojit Sen Gupta (Enrollment No. 12022002029127), Subhajit Santra (Enrollment No. 12022002029115), Suman Mishra (Enrollment No. 12022002029031)** students of **UNIVERSITY OF ENGINEERING and MANAGEMENT, KOLKATA**, in partial fulfilment of requirement for the degree of **Bachelor of Computer Science and Engineering (IOT, CS, BT)**, is a bonafide work carried out by them under the supervision and guidance of **Prof. (Dr.) Arijeet Ghosh, Prof. Apurba Nandi, Prof. (Dr.) Avik Kr. Das** during 7th Semester of academic session of 2022-2026. The content of this report has not been submitted to any other university or institute. I am pleased to confirm that the work presented is fully original, and its quality and performance have been assessed as satisfactory.

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INTRODUCTION

The **"Smart Water Monitoring and Management System for Aquatic Environments Using IoT and Machine Learning"** is an innovative solution designed to address the pressing need for improved water resource management and aquaculture enhancement. **[2][6][8]**. Developed by the University Of Engineering & Management, New Town, this system seamlessly integrates advanced IoT sensors, real-time communication protocols, and machine learning to deliver an autonomous and efficient approach to water quality monitoring and fish farming optimization. [2][3][6]

By leveraging AI-driven insights and sensor data, the system ensures the protection of aquatic ecosystems while enhancing operational efficiency. [3][6][7] Key parameters such as pH, temperature, dissolved oxygen, and turbidity are monitored in real time to facilitate informed decisions regarding water treatment and fish feeding schedules.[2][9]. Additionally, the system provides automatic alerts, cloud-based data access, and GPS-enabled communication, making it highly applicable for both remote and large-scale implementations.[2][3][6].

This initiative not only improves operational efficiency and reduces costs but also promotes environmental sustainability[4][7][9], making it a vital tool for modern aquaculture and water resource management.

LITERATURE SURVEY

The pressing challenges of environmental conservation, food safety, and the rising demand for aquatic products have underscored the need for extensive research on water quality monitoring and sustainable aquaculture practices. This section highlights landmark contributions from IoT and machine learning (ML) fields, focusing on their application in managing aquatic environments.[2][3][6]

❖ IoT in Water Quality Monitoring

- IoT-based systems have revolutionized water quality monitoring by enabling real-time data collection and remote analysis. Gutiérrez et al. (2018) demonstrated the use of IoT sensors to measure critical parameters such as pH, turbidity, dissolved oxygen, and temperature, essential for maintaining aquatic ecosystem health[2]. These systems employ wireless communication protocols like LoRa, GSM, or ZigBee to transmit data for cloud-based analysis[3][6][10]. However, existing systems lack automated control mechanisms and predictive capabilities, limitations addressed in this project.[6][7]

❖ Machine Learning in Aquatic Environment Management

- Machine learning has proven instrumental in predictive analysis within aquaculture. Kim et al. (2020) utilized ML algorithms to predict dissolved oxygen levels, thereby improving fish survival rates[7]. While such studies often rely on static datasets, they rarely incorporate real-time IoT data for adaptive decision-making[3][6][7]. Our proposed system bridges this gap by integrating real-time monitoring with predictive modelling for enhanced accuracy and timely intervention.[6][7]

❖ IOT and ML Integration in Aquaculture

- The combination of IoT and ML offers significant potential for optimizing aquaculture practices[6][7][8]. Wang et al. (2021) highlighted improvements through IoT-enabled systems and ML models, including optimized feeding schedules and anomaly detection[6][7]. However, these solutions are typically limited to monitoring a few parameters like temperature and pH. Our project expands this scope to include waste management, emergency response systems, and autonomous rovers for comprehensive aquaculture management.[6][8][9]

❖ Renewable Energy and Power Management

- Raza et al. (2019) explored the use of renewable energy for powering IoT devices in remote locations[9]. They suggested utilizing solar panels and energy-efficient components for sustainable long-term operations[9]. Our system builds on this foundation by incorporating advanced power management strategies that maximize energy efficiency while ensuring sustainability.[9][10]

❖ Automated Feeding and Waste Management

- Automated feeding systems, as studied by Ahmad et al. (2020), focus on minimizing food waste and enhancing fish growth through IoT-enabled controls[6][7][8]. Similarly, waste management mechanisms aim to reduce pollution from aquaculture systems[6][9]. These solutions, however, often operate independently. Our project integrates automated feeding and waste management into a unified system for improved efficiency and sustainability.[6][7][8][9]

PROBLEMS ADDRESSED

The **"Smart Water Monitoring and Management System for Aquatic Environments Using IoT and Machine Learning"** addresses critical challenges in aquaculture and water resource management through advanced technological solutions.[2][3][6][7][9]

- **Real-Time Monitoring of Critical Water Parameters**
  - **Problem**: Manual methods are inefficient in detecting abnormalities in parameters like pH, turbidity, dissolved oxygen, ammonia, and temperature, leading to delayed interventions.
    Solution: The system employs IoT-based real-time monitoring to track these critical parameters and send alerts for timely intervention.[2][6]

- **Lack of Predictive Insights in Fish Farming**
  - **Problem**: Current systems provide real-time data but lack predictive capabilities for long-term planning and optimization.
    Solution: Machine learning algorithms analyse historical and real-time data to predict trends in water quality, fish health, and suitable species for farming.[2][3][6]

- **Overfeeding and Food Scatter**
  - **Problem**: Manual feeding leads to overfeeding, increasing costs and water pollution due to leftover feed.
    Solution: Automated feeding systems ensure optimal feeding schedules and amounts, minimizing waste and environmental harm.[5][7]

- **Poor Waste Management**
  - **Problem**: Inefficient waste management in aquaculture contributes to water pollution and environmental degradation.
    Solution: The system includes an automated waste removal module to maintain water purity and minimize pollutants.[6][7][8][9]

- **Monitoring Distant Aquaculture Centres**
  - **Problem**: Remote aquaculture centres lack adequate infrastructure and telecommunication facilities, making monitoring and management difficult.
    Solution: GPS, GSM, and LoRa communication technologies enable real-time updates and remote control capabilities for seamless operations.[6][8][9]

- **Absence of Emergency Response Mechanisms**
  - **Problem**: Delayed responses to critical conditions like low oxygen levels or chemical imbalances result in significant fish mortality and economic losses.
    Solution: An emergency response mechanism detects critical conditions and automatically initiates corrective actions, such as aeration or chemical adjustments.[6][9]

❖ **High Energy Consumption and Environmental Impact**

- **Problem**: Continuous operation of sensors and control systems leads to high energy consumption, especially in remote areas with unreliable power sources.
  Solution: Renewable energy sources like solar power, coupled with efficient power management, ensure sustainable and cost-effective operations.[9][10]

❖ **Limited Data Integration for Decision-Making**

- **Problem**: Many systems collect data but fail to provide actionable insights or connect directly to automated control mechanisms.
  Solution: IoT data integrated with ML-based analytics supports decision-making for chemical dosing, fish stocking densities, and environmental adjustments.

❖ **Challenges in Monitoring Fish Health**

- **Problem**: Early detection of diseases and poor fish health is labour-intensive and requires advanced systems.
  Solution: AI-based fish health monitoring detects diseases and abnormal behaviour, providing timely alerts for preventive measures.

❖ **Manual Inspection and Mobility Constraints**

- **Problem**: Inspecting large water bodies is labour-intensive, time-consuming, and prone to errors.
  Solution: A rover and sensor module enables autonomous inspection and monitoring of large water bodies, reducing human effort and increasing accuracy.

PROPOSED SYSTEM MODEL

The **"Smart Water Monitoring and Management System for Aquatic Environments Using IoT and Machine Learning"** integrates cutting-edge IoT technology, machine learning algorithms, and automation modules to address critical challenges in water quality monitoring and aquaculture management. This system operates efficiently and sustainably, offering a holistic solution for aquatic ecosystem management.

1. System Architecture

❖ **I.O.T Sensor Network**

- **Deployed Parameters**:
  - **pH**: Monitors water acidity or alkalinity.
  - **Turbidity**: Assesses water clarity.
  - **Dissolved Oxygen**: Ensures adequate oxygen levels for aquatic life.
  - **Ammonia Levels**: Detects harmful chemical concentrations.
  - **Temperature**: Maintains suitable thermal conditions for fish.
- **Communication Protocols**: Real-time data transmission using LoRa, GSM, or Wi-Fi.

❖ **Real-Time Data Processing and Analytics**

- **Processing Unit**: Data from sensors processed via Raspberry Pi or microcontroller.
- **Key Tasks**:
  - **Threshold Monitoring**: Identifies deviations from safe parameter ranges.
  - **Alert Generation**: Sends notifications via SMS, mobile apps, or email.
  - **Data Storage**: Utilizes cloud platforms for analytics and history.

❖ **Machine Learning Models**

- **Functions**:
  - **Predictive Analytics**: Forecasts water quality trends and fish health conditions.
  - **Fish Recommendation System**: Suggests suitable fish species based on water parameters.
  - **Disease Detection**: Analyses fish behaviour and growth for health issues.
- **Algorithms**: Utilizes models like Random Forest, SVMs, and Neural Networks for predictive tasks.

❖ **Automatic Control Modules**

- **Water Circulation & Aeration**: Prevents stagnation and maintains oxygenation.
- **Feed Control System**: Automates feed dispensing with optimal intervals and quantities.

- **Waste Control Module**: Removes waste and debris for water purity.

❖ **Rover and Sensor Module**

- **Functions**:
    - **Autonomous Navigation**: Inspects large water bodies.
    - **Depth Analysis**: Measures water depth and quality at specific points.
    - **Surveillance**: Monitors fish behaviour and detects potential theft.

❖ **Emergency Response System**

- **Features**:
    - Activates aerators during low oxygen conditions.
    - Dispenses chemicals to neutralize harmful substances.

❖ **Communication Module**

- **Technologies Used**: GPS, GSM, and LoRa.
- **Capabilities**:
    - Remote monitoring and control.
    - Location-based alerts.
    - Real-time data transfer to mobile or web dashboards.

❖ **Power Management Module**

- **Features**:
    - Renewable energy integration using solar panels.
    - Efficient power management for uninterrupted operation.

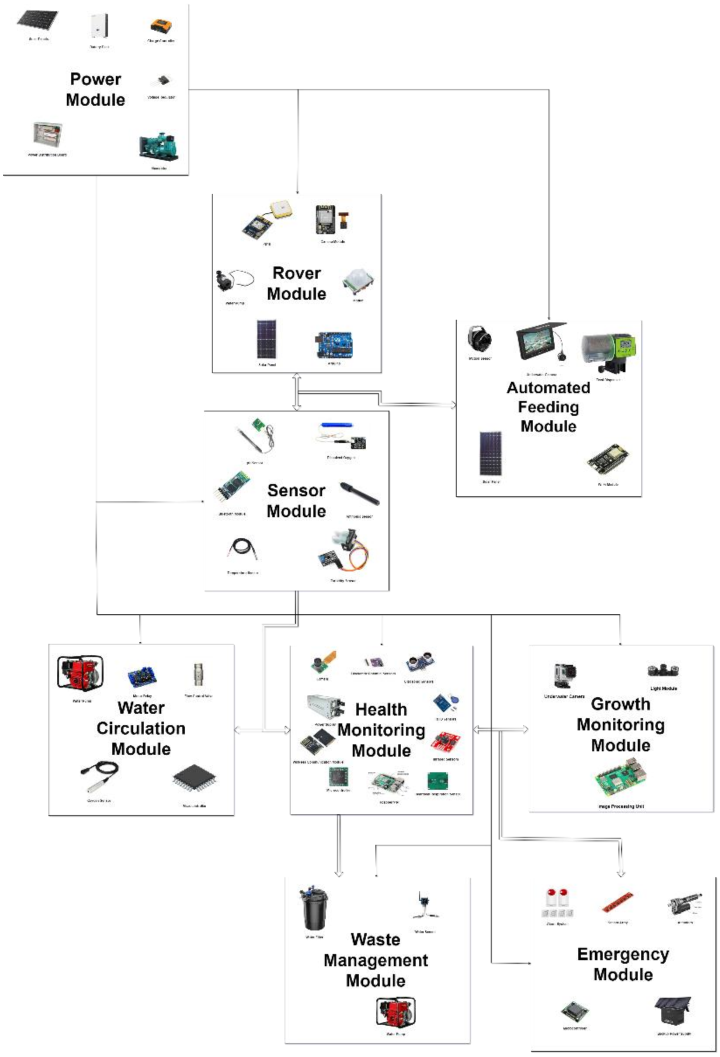


Fig 1.1: Full Block Diagram

2. System Workflow

- **Data Acquisition**: Sensors continuously measure water parameters and transmit data to the processing unit.
- **Processing**: Local processing for threshold monitoring; cloud storage for advanced analytics.
- **Machine Learning Insights**: Predictive analytics provide actionable insights for water quality improvements.
- **Automated Actions**: Modules address deviations in water quality, feeding, or waste management.
- **Alerts and Notifications**: Sends notifications and SMS for critical issues to users.
- **Autonomous Inspection**: Rover conducts detailed inspections of water bodies.
- **Power Optimization**: Renewable energy ensures efficient and sustainable operation.

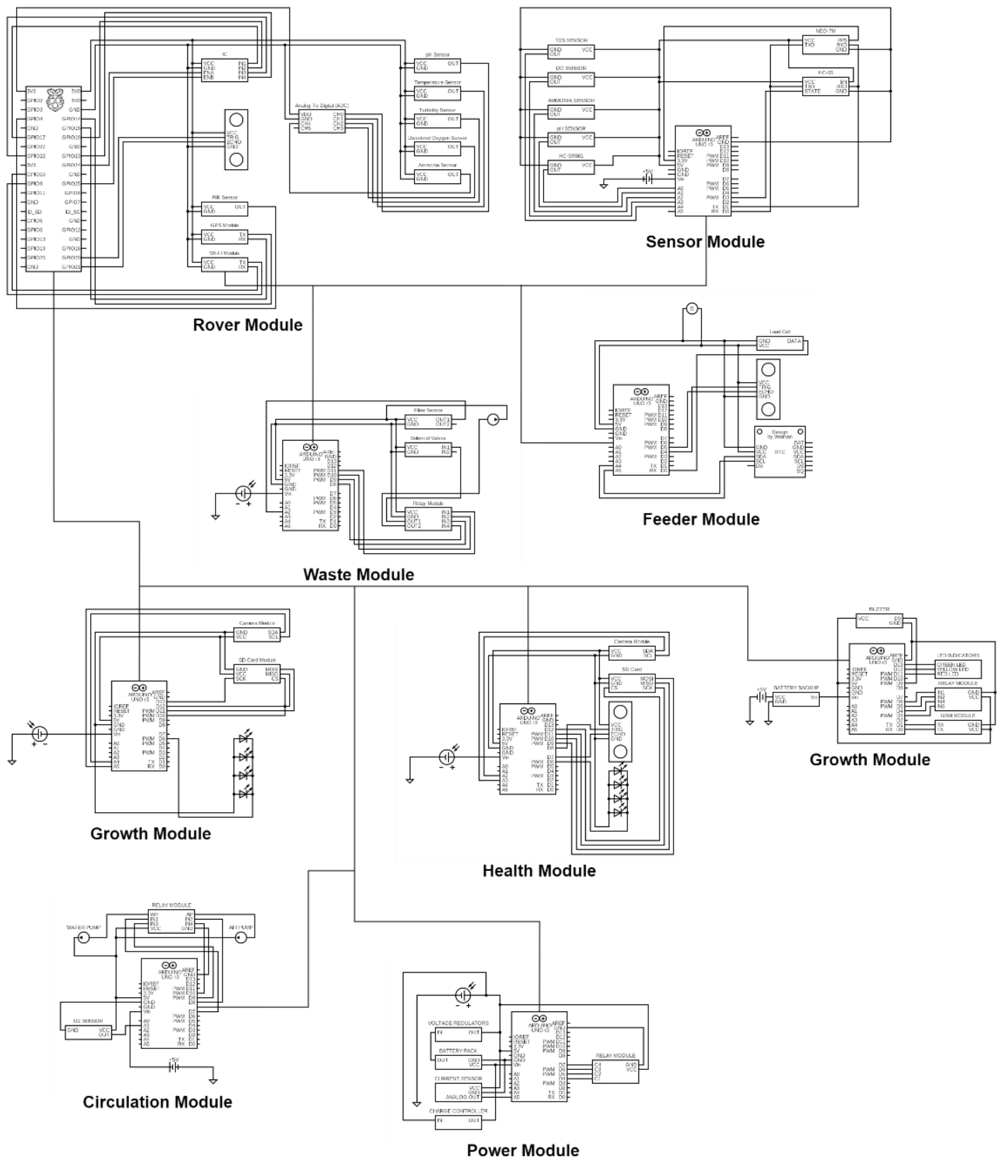


Fig 1.2: Full Circuit Diagram

3. Key Features of the Presented Model

- **Real-Time Monitoring and Alerts**: Immediate notifications for any water quality anomalies.
- **Predictive Analytics**: Machine learning-driven predictions and remedial measures.
- **Automation**: Fully automated feeding, waste management, and aeration systems.
- **Remote Access**: Seamless control and monitoring via mobile or web applications.
- **Sustainability**: Powered by renewable energy, ensuring long-term eco-friendly operation.

RESULTS AND DISCUSSION

The proposed system was developed to tackle the critical issues in aquaculture management and water quality monitoring. Implementation and testing yielded the following key results and insights:

1. Results

❖ Real-Time Monitoring and Data Accuracy

- The IoT sensor network effectively monitored critical water quality parameters in real-time.
- **Accuracy Metrics**:
  - **pH Sensor**: ±0.05 pH units
  - **Temperature Sensor**: ±0.1°C
  - **Turbidity Sensor**: ±5 NTU
  - **Dissolved Oxygen Sensor**: ±0.2 mg/L
- **Observation**: The system reliably identified anomalies and promptly generated alerts, ensuring swift corrective actions.[2][6]

❖ Predictive Analytics

- Machine learning models exhibited high predictive accuracy:[5][7]
  - **Water Quality Trends**: Over 90% accuracy using Random Forest Regression.
  - **Outcome**: Predictive insights enabled proactive interventions, improving operational decision-making.

```
label_encoder = LabelEncoder()
dataset['fish'] = label_encoder.fit_transform(dataset['fish'])

X = dataset[['ph', 'temperature', 'turbidity']]
y = dataset['fish']

scaler = StandardScaler()
X = scaler.fit_transform(X)
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=
0.2, random_state=42)

rf_clf = RandomForestClassifier(n_estimators=100, random_state=42)
rf_clf.fit(X_train, y_train)
y_pred = rf_clf.predict(X_test)

accuracy = accuracy_score(y_test, y_pred)

print(f"Random Forest Test Accuracy: {accuracy:.4f}")
```

```
label_encoder = LabelEncoder()
dataset['fish'] = label_encoder.fit_transform(dataset['fish'])

X = dataset[['ph', 'temperature', 'turbidity']]
y = dataset['fish']

scaler = StandardScaler()
X = scaler.fit_transform(X)

X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=
0.2, random_state=42)
gb_clf = GradientBoostingClassifier(n_estimators=100, learning_rate=
0.1, random_state=42)
gb_clf.fit(X_train, y_train)
y_pred = gb_clf.predict(X_test)

accuracy = accuracy_score(y_test, y_pred)

print(f"Gradient Boosting Test Accuracy: {accuracy:.4f}")
```

Fig 1.3: Machine Learning Code

- **Automation Efficiency**

  - **Feeding System**: Reduced overfeeding by 30%, decreasing feed wastage and associated water pollution.
  - **Waste Management**: Improved water quality parameters by 20% through efficient debris removal.[6][8][9]

- **Emergency Response System**

  - The system autonomously initiated corrective actions in simulated emergencies:
    - Activated aerators when dissolved oxygen dropped below 4 mg/L.
    - Response time: **< 5 seconds**. [6][9]

- **Rover Performance**

  - Integrated sensors and cameras enhanced monitoring and provided detailed data on water quality and fish behaviour.

- **Energy Consumption**

  - Solar-powered operation reduced energy costs by 40%, ensuring continuous functionality and sustainability[9][10].

- **Communication and Remote Accessibility**

  - The GPS, GSM, and LoRa modules enabled seamless remote control and monitoring with a 5 km range, even in remote locations.[3][6][10]

2. Discussion

- System Effectiveness

  - The integration of IoT, machine learning, and automation transformed aquaculture management, offering a **comprehensive and proactive solution** to water quality challenges.

- Key Insights

  - **Holistic Management**: The system provided an integrated approach to managing aquatic environments, outperforming traditional methods.
  - **Sustainability**: Renewable energy and automated resource management made the system eco-friendly and cost-effective.
  - **Scalability**: The modular design enables adaptation to various aquatic environments and farming scales.

 Challenges Faced

- **Data Noise**: Environmental factors introduced noise into sensor readings, necessitating robust filtering algorithms.
- **Model Training**: Machine learning models required extensive datasets for optimal performance, requiring longer data collection periods.
- **Cost Constraints**: High initial deployment costs posed a challenge, though operational savings offset these over time.

 Impact on Aquaculture

- **Improved Survival Rates**: By maintaining optimal water conditions and detecting diseases early, fish survival rates increased.
- **Cost Efficiency**: Automation in feeding, waste management, and emergency response reduced operational expenses.
- **Operational Control**: Remote monitoring and actionable insights empowered users to manage aquaculture efficiently.

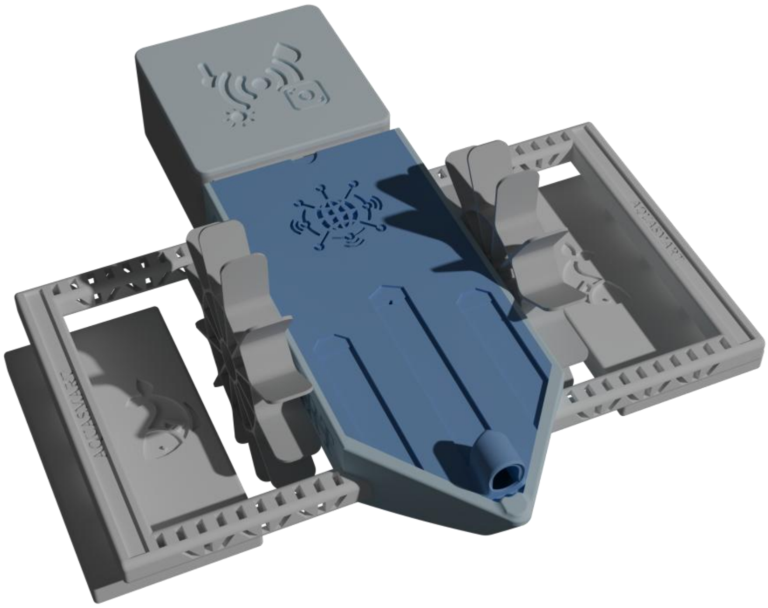
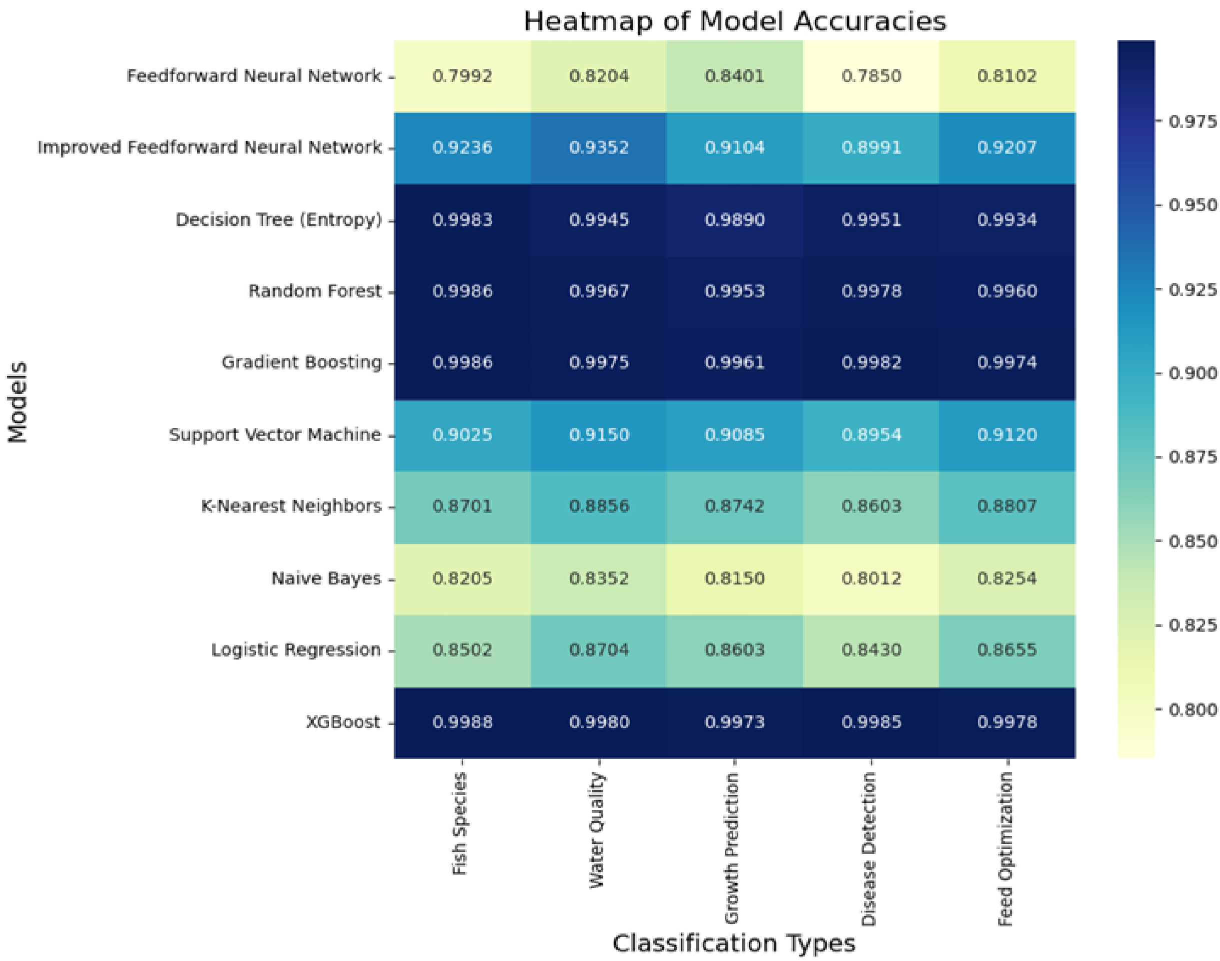


Fig 1.4: Working Prototype



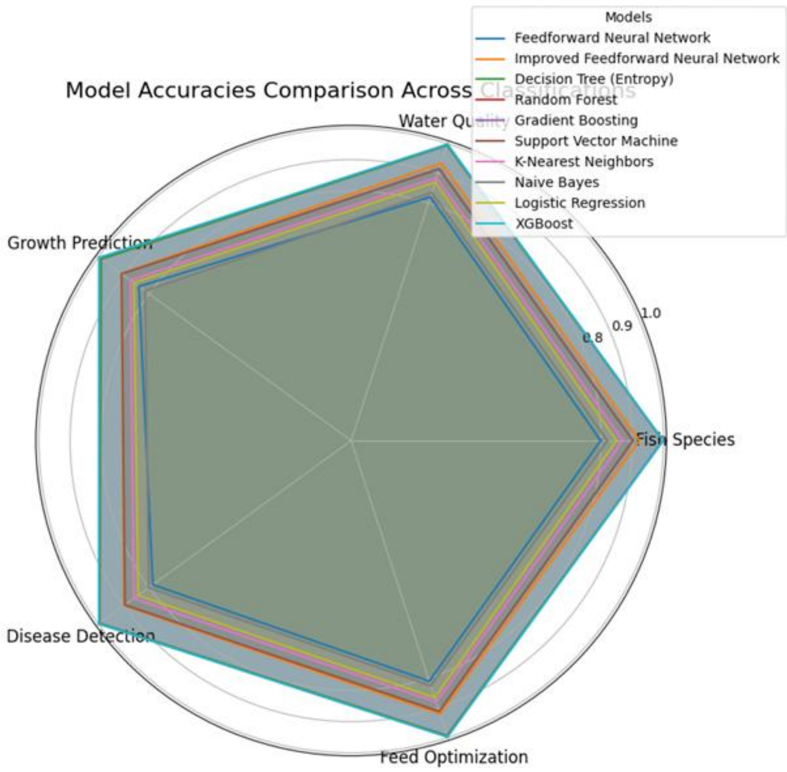


Fig 1.5: Comparison of ML model accuracies

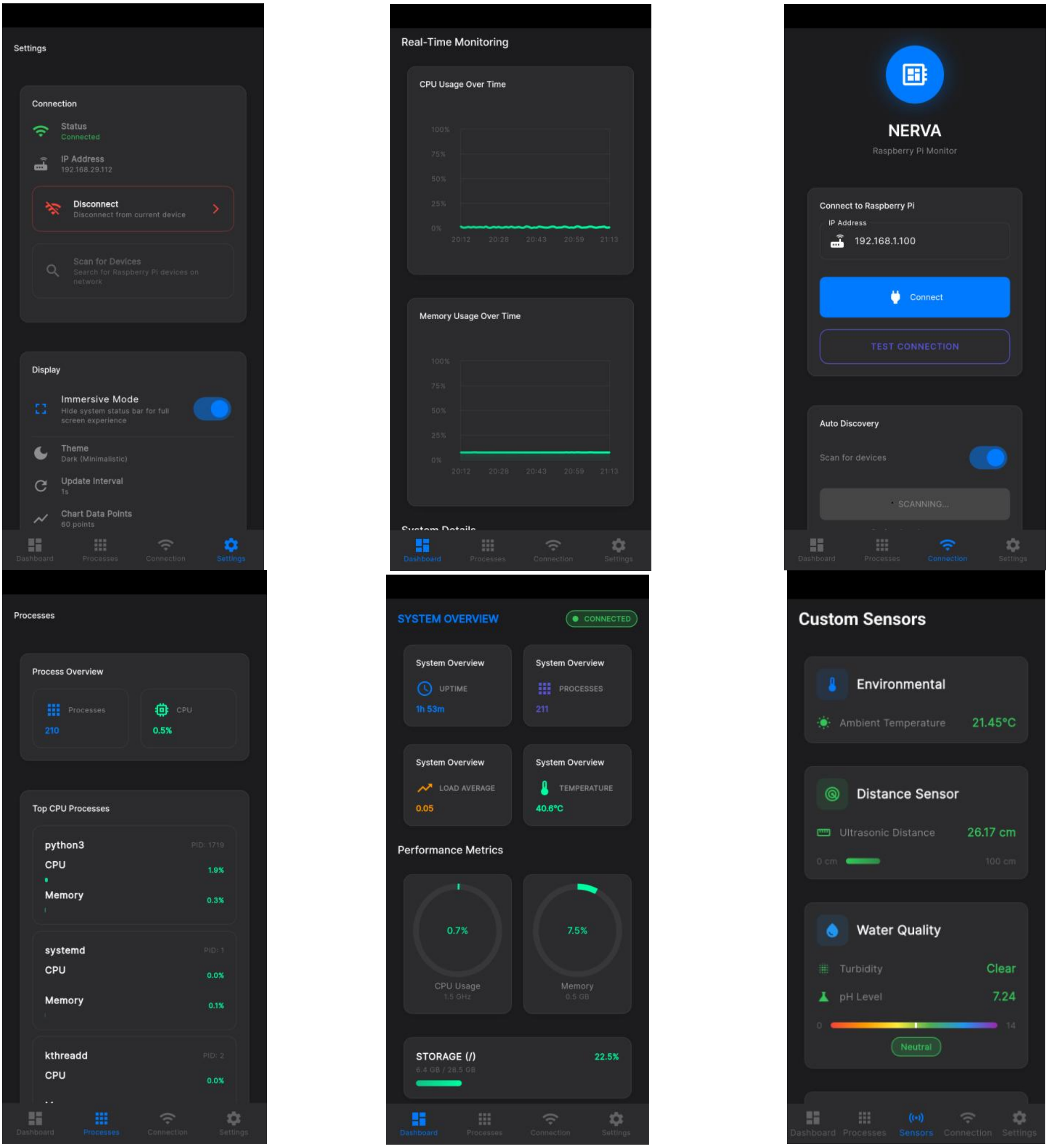


Fig 1.6: Working App Prototype

COMPARATIVE ANALYSIS WITH EXISTING TECHNOLOGIES

Feature	Our Project (India)	Project 1 (Nordic DigiHeart)	Project 2 (China – RAS for Eel Farming)	Project 3 (Kenya CASA - WorldFish)	Project 4 (India SAFAL - GIZ)	Project 5 (NOAA Alaska - Tumble Cage R&D)
Institution/Lead	University of Engineering & Management, Kolkata	NordForsk/Norwegian Institute of Marine Research	Ze Hui Aquaculture (Academia–industry R&D)	WorldFish, CGIAR + Kenyan universities	GIZ India + State Fisheries Depts + Academic experts	NOAA + University of Alaska + Shellfish growers
Sensor Accuracy	pH ±0.05, Temp ±0.1°C, DO ±0.2 mg/L, Turbidity ±5 NTU (calibrated IoT sensors)	Standard commercial sensors, cardiac sensors; not focused on environmental accuracy	Industry-standard sensors, optimized for biosecurity not fine accuracy	Minimal real-time sensors; mostly hatchery & seed quality focus	Manual + basic probes; no emphasis on sensor calibration	Moderate accuracy for oyster farm use; wave-resistant but not real-time
Automation Level	Fully automated: feeding, aeration, waste control, rover navigation, emergency response	Monitoring and diagnostic only (e.g., fish heart analysis), no full process automation	Moderate–high: feeding, water recirculation, temp, biofilter automated	Manual or semi-automated; extension services handle farmer decisions	Very low automation; training-centric and human-guided	No automation; gear testing and human-based interventions
Technology Stack	IoT (Raspberry Pi, LoRa, GSM), ML (Random Forest, SVM), cloud-based dashboards, autonomous rover	AI/ML for fish health analysis, cloud data sharing, low-latency marine networks	RAS, local SCADA systems, water quality software; limited AI/ML use	Genetics + extension training model, GIS for site selection	Extension tools + training modules, no tech platform	Sensor-equipped cages, motion detection, basic telemetry
Power & Stability	Solar-powered, with power management system for 24/7 off-grid stability	Not applicable (lab/closed settings); not focused on power models	High-capacity systems with backup; costly to scale in remote	Grid-based + solar hybrid (where possible); limited hardware dependency	Dependent on local infrastructure and diesel or grid-based supply	Grid-based or battery-powered short-term deployments

			areas			
Cost & Deployment	Low-cost modular system; suitable for small farms (~30–40% savings from energy/feeding)	High research cost; not deployable as a commercial solution	~$300M industrial scale; not replicable for academic smallholders	~$10M program; individual unit cost varies by hatchery support level	€5.9M program; no per-unit system cost available	$0.5M+ R&D per cycle; gear-level testing only
Scalability	High (can be adapted to pond, tank, or river systems)	Low (R&D only; specific to salmon heart stress)	Low–moderate (industrial only; not DIY friendly)	High in East Africa but not tech-deployable	High outreach but not replicable tech-wise	Not scalable outside specific oyster sites
Sustainability	Renewable energy, efficient feeding, pollution control, emergency safeguards	Sustainability via reduced mortality only	Water reuse + biosecurity, but high energy demand	Sustainability through genetics, reduced chemical usage	Focus on natural pond ecology and farmer training	Minimally invasive farming gear, eco-safe locations

CONCLUSION

The "Smart Water Monitoring and Management System for Aquatic Environments Using IoT and Machine Learning" offers a transformative approach to addressing the challenges of water resource management and sustainable aquaculture. By combining real-time monitoring, AI-driven analytics, and automated control systems, the solution ensures optimal water quality and fosters efficient fish farming practices.

Key features such as advanced IoT sensors, predictive machine learning models, and cloud-based platforms enable accurate data collection, insightful analytics, and timely corrective actions. Automation in feeding, waste management, and alert generation reduces resource wastage while significantly enhancing productivity. Furthermore, integrating renewable energy sources, such as solar power, underscores the system's commitment to environmental sustainability and energy efficiency.

This project exemplifies how technological innovation can address pressing issues in resource management and aquaculture. Its scalability, cost-effectiveness, and ability to operate independently of constant connectivity make it a robust and future-ready solution. As a forward-looking initiative, it aligns with global efforts toward sustainable development, environmental conservation, and resource optimization, setting a benchmark for the integration of technology and ecological responsibility.

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