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Design of Hydrosentinel for Matsya Using Image Processing Technique

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Abstract

The HydroSentinal is an innovative fish health monitoring system designed to enhance aquaculture management through advanced image processing techniques. Specifically developed for Matsya (fish) applications, the system captures high-resolution underwater images of fish gills and body features using corrosion-resistant, camera-integrated platforms such as RC boats. Captured images are processed using color-based segmentation, edge detection, and machine learning algorithms to detect abnormalities, including inflammation, discoloration, or parasitic infections. By providing real-time health assessments, the HydroSentinal enables early intervention, reducing fish mortality and improving yield. In addition to health monitoring, the HydroSentinal can be integrated with water quality sensors to measure parameters such as temperature, pH, and turbidity, creating a comprehensive aquatic ecosystem assessment tool. The device's portability and corrosion-resistant materials make it well-suited for deployment in rural and village settings. The system's data analytics capabilities allow trends to be tracked over time, enabling farmers and aquaculture managers to make informed decisions regarding stocking density, feed schedules, and disease control measures. By reducing reliance on manual inspections and costly laboratory tests, HydroSentinel promotes cost-effective and sustainable aquaculture practices. Its modular design further allows future integration of autonomous navigation, wireless data transfer, and cloud-based dashboards for remote monitoring. The HydroSentinel thus represents a scalable, field-ready innovation that combines mechanical design, embedded systems, and computer vision to improve fish welfare, optimize resources, and support sustainable aquaculture development in diverse water environments.

Keywords
RC boat, image processing technique, fish health, real time monitoring.

1. Introduction

Aquaculture plays a vital role in ensuring food security and supporting rural livelihoods, yet fish health monitoring remains a major challenge due to traditional reliance on manual observation. To address this gap, the Hydro Sentinel for matsya is proposed as an intelligent, low-cost system that integrates an RC boat with onboard sensors and image processing techniques for real-time fish health assessment. By capturing underwater images and analyzing them for abnormalities in gills, skin, and behavior, the system enables early detection of diseases while also monitoring water quality parameters. This approach not only reduces human effort but also provides a sustainable, technology-driven solution aligned with the vision of "Tech for Good," making it especially relevant for village and community applications. The system captures underwater images and analyzes them for abnormalities in gills, skin, body texture, and behavioral patterns, thereby enabling early detection of diseases. Simultaneously, it monitors critical water quality parameters such as pH, dissolved oxygen, turbidity, temperature, and conductivity, providing a holistic understanding of the aquatic environment. By combining IoT-based sensing with AI-driven image processing, Hydro Sentinel minimizes human intervention while maximizing accuracy and efficiency. This not only reduces operational costs for farmers but also ensures healthier fish yields, improved productivity, and lower mortality rates. Furthermore, its portable and scalable design makes it adaptable to diverse water bodies, from village ponds to larger aquaculture farms. In the long term, such systems can foster smarter water resource management, safeguard aquatic biodiversity, and play a key role in achieving food security at both local and national levels.

1.1 Objectives

- Develop a remote-controlled boat integrated with IoT sensors to monitor water quality parameters such as pH, dissolved oxygen, turbidity, temperature, and conductivity.
- Equip the boat with a high-resolution underwater camera for capturing imagery to assess fish species, population, and health status using image processing techniques.
- Enable real-time wireless transmission of collected data to a central server or cloud platform for continuous monitoring and analysis.
- Analyze aquatic environmental conditions by comparing sensor data against species-specific tolerance limits to evaluate habitat suitability.
- Provide timely insights and alerts to support conservation efforts, pollution detection, and sustainable management of aquatic ecosystems.
- Design a scalable, autonomous system capable of operating in diverse water bodies, ensuring ease of use and minimal human intervention.

2. Literature Review

Sensorized and IoT-based aquatic monitoring has been a major focus. Libu Manjakkal et al. highlighted that sensorised tools deployed on buoys, boats, and ships can effectively gather environmental data from various water bodies. However, they stressed a persistent gap in data quality, collection, and analysis due to the absence of standardized approaches and the complexity of spatiotemporal water parameter variations. Similarly, Johanne Paulo S et al. (2023) developed an IoT-enabled remote-controlled boat with GPS navigation, capable of measuring pH, EC/TDS, temperature, and coordinates, transmitting the data in real time to a central server. Samia Islam et al. (2019) proposed a multi-sensor IoT system integrated with an Arduino Uno and desktop application, using machine learning (fast forest binary classifier) for classification of water quality data.

Marine environmental monitoring and hazard management has also been addressed. Chitra Sabapathi et al. (2017) investigated marine monitoring, covering environmental parameters, marine life behavior, and human activities. Tara Maguire et al. (2023) demonstrated that IoT technologies, including smart boats and underwater drones, are effective in detecting and mitigating marine ecological hazards such as oil spills, pollution, and invasive species, with additional capabilities for marine animal tracking and conservation planning.

OSIL Smart Buoy (2024) – Ocean Scientific International Ltd developed an AI-powered buoy system equipped with multiparameter water-quality sensors and GSM telemetry. These buoys not only collect data such as pH, dissolved oxygen, turbidity, and salinity but also integrate predictive AI models to forecast contamination events, improving cost efficiency and reducing the frequency of manual sampling.

Miros Oil Spill Monitoring (2024) – Miros, in collaboration with Belga Marine, enhanced oil spill detection using a cloud-enabled IoT platform integrated with AI-based radar analysis. Their system provides real-time detection and tracking of marine oil slicks, with predictive models to estimate drift and spread. This highlights how IoT combined with cloud and AI can improve hazard management, regulatory compliance, and ecological protection.

Expanding on these approaches, Rajitha et al. (2020) designed an IoT-based smart water quality monitoring system that continuously measured parameters such as pH, turbidity, and dissolved oxygen, transmitting the results to a cloud platform for real-time monitoring and sustainable water management. Likewise, Mehta et al. (2021) presented an autonomous aquatic monitoring vehicle equipped with multiple sensors and wireless communication modules, capable of capturing temperature, pH, and turbidity data with minimal human intervention, demonstrating how automation and IoT integration can improve efficiency and scalability in aquatic ecosystem monitoring.

Zhang et al. (2022) demonstrated a low-power IoT-based monitoring system combining wireless sensor networks with cloud computing for continuous water quality analysis, highlighting the importance of energy.

3. Method

The Hydro Sentinel boat operates by integrating sensors and cameras to continuously capture water quality parameters and fish images from the aquatic environment. These inputs are processed using image processing and machine learning algorithms to detect fish health conditions accurately and in real time.

3.1 Methodology

3.1.1 System Initialization and Data Acquisition

The operation of the Hydro Sentinel system begins with initialization, where the RC boat and its integrated modules are powered on, calibrated, and synchronized to ensure reliable performance. Once deployed into the water body, the system immediately starts collecting data through onboard IoT sensors that measure critical water quality parameters such as temperature, turbidity, pH, dissolved oxygen, and water level. These parameters are essential indicators of aquatic health, influencing fish metabolism, growth rates, and overall ecosystem balance. In parallel, a waterproof high-resolution camera captures continuous underwater footage, enabling direct visual observation of fish populations. The captured images undergo real-time processing using computer vision algorithms to detect anomalies in fish skin, gills, and body patterns, while also monitoring behavioral aspects like swimming speed, grouping patterns, and feeding activity, which are often early indicators of disease or stress.

3.1.2 Wireless Transmission and Remote Monitoring

The sensor readings and processed image data are packaged and transmitted wirelessly to a ground station or cloud platform using Wi-Fi, GSM, or LoRa communication protocols, depending on deployment requirements. This eliminates the need for manual data retrieval and allows stakeholders to access information remotely. At the receiving end, the transmitted data is stored, analyzed, and visualized through an interactive dashboard that presents key metrics, trends, and alerts. For instance, if dissolved oxygen drops below safe limits or if fish exhibit unusual lethargic behavior, the system generates warnings to prompt timely intervention.

3.1.3 Continuous Monitoring for Sustainable Aquaculture

The entire setup functions as a continuous monitoring loop, where data collection, processing, transmission, and analysis occur in real time, ensuring uninterrupted oversight of the aquatic environment. This approach not only enhances accuracy compared to traditional manual sampling but also minimizes labor, reduces operational costs, and increases scalability across diverse water bodies such as ponds, reservoirs, or village aquaculture farms. By integrating IoT, wireless communication, and AI-driven image processing, the Hydro Sentinel system provides a comprehensive, autonomous, and technology-driven solution that supports sustainable aquaculture practices, early disease detection, and proactive water management.

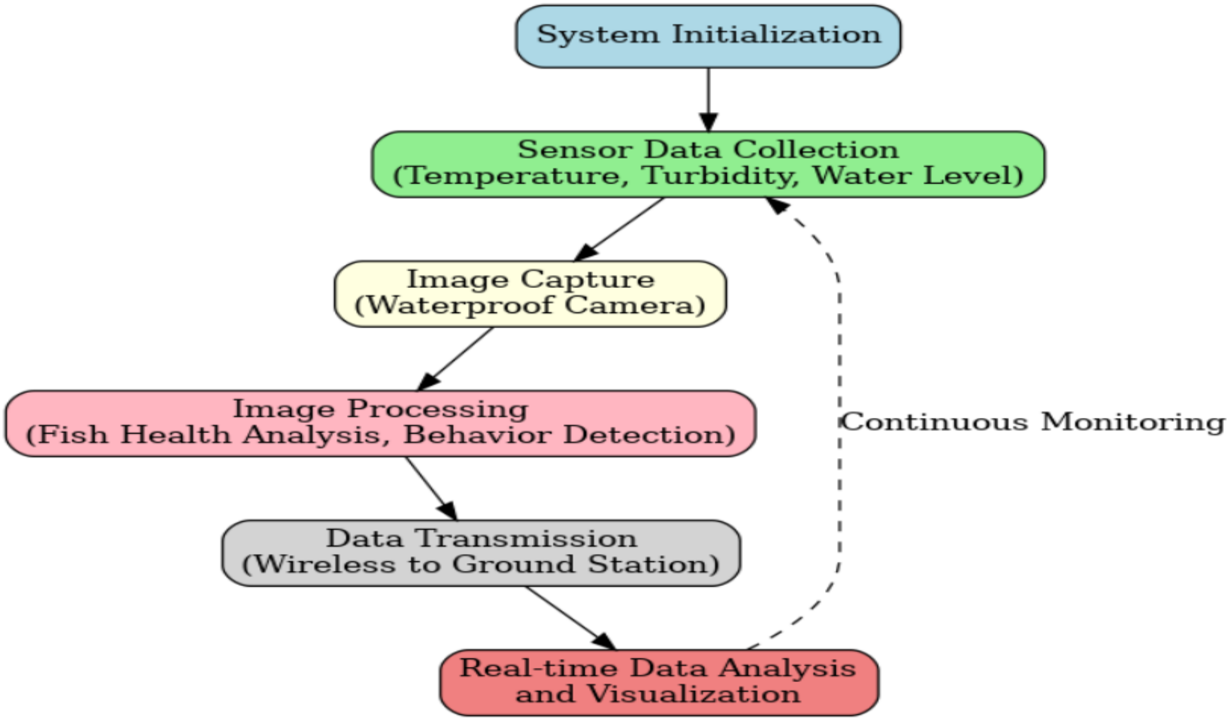

Figure 1. Workflow of the Hydro Sentinel Monitoring System

This project focuses on the design and development of a remote-control boat equipped with advanced sensors and image processing techniques to monitor water quality and fish health in real-time. The boat integrates various environmental sensors, including temperature, turbidity, and water level sensors, to track key parameters such as water temperature, pollution levels, and turbidity. Additionally, a waterproof camera is used for fish health monitoring through image processing algorithms, which analyses fish behavior, detect signs of disease, and assess overall health. The data from these sensors and images are transmitted wirelessly to a ground station for real-time analysis and visualization. The system aims to provide an efficient, mobile solution for environmental monitoring in aquatic ecosystems, contributing to improved fish health management and water quality assessment. The combination of sensor-based data collection and image processing offers a comprehensive approach to monitoring aquatic environments, with potential applications in fisheries, environmental science, and aquaculture

3.2 Design of Hydrosentinel Device

The Hydro Sentinel boat is designed as a compact, lightweight, and stable platform capable of navigating ponds, reservoirs, and aquaculture farms. Its hull is shaped to provide buoyancy and balance, ensuring smooth movement even in shallow or disturbed water. The layout incorporates dedicated sections for the propulsion system, battery housing, and electronic modules, all enclosed in waterproof casings for protection. Sensors such as temperature, turbidity, and water level probes are mounted at the base for accurate environmental readings, while a waterproof camera is positioned at the front to capture clear underwater images of fish. Communication modules like GPS, Bluetooth, and Wi-Fi/GSM are integrated on the upper deck for efficient data transfer and location tracking. This modular design not only simplifies maintenance and scalability but also ensures energy efficiency, portability, and reliable real-time aquatic monitoring (Figure 2).

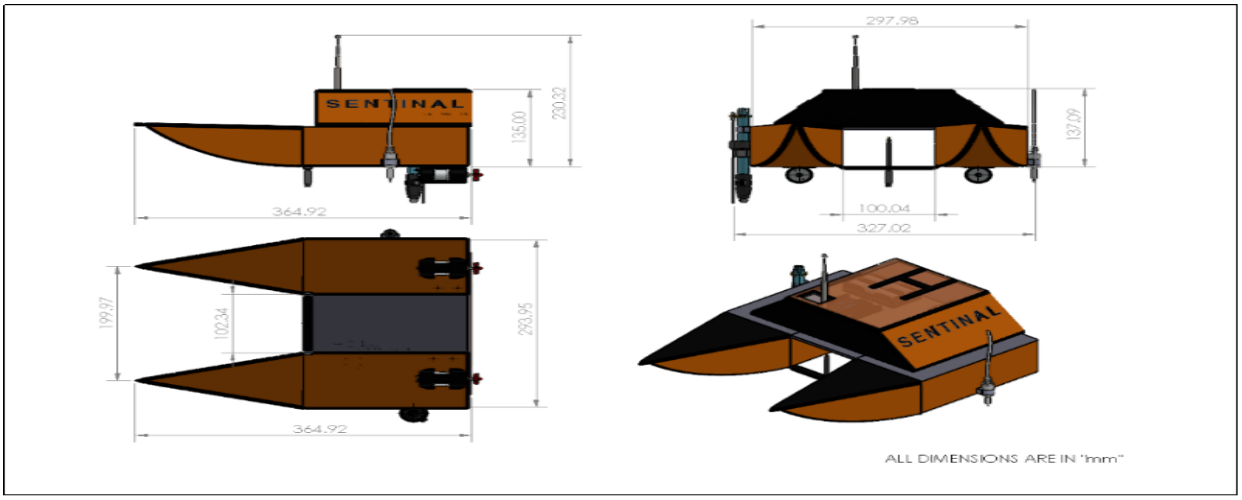

Figure 2. Design of hydrosentinel boat

Figure 3. Components

Figure 3 illustrates the major components of the RC boat used for aquatic monitoring. The boat integrates environmental sensors (temperature, turbidity, water level, and dissolved oxygen) for water quality assessment,along with a GPS module for location tracking and navigation. A Bluetooth module is included for short-range communication, while other wireless technologies like Wi-Fi or GSM enable remote data transfer.

4. Data Collection

Dataset Preparation

Data collection begins with the creation of a comprehensive dataset of fish images, representing both healthy and infected conditions. High-resolution images are captured under controlled lighting and water environments to ensure clarity. This dataset forms the foundation for training the classification model, as it provides a wide variety of examples of lesions, discoloration, and normal features that are essential for accurate recognition.

Feature Extraction

Once the dataset is collected, image processing techniques such as resizing, filtering, segmentation, and edge detection are applied to enhance the important features of the fish images. From these processed images, **feature vectors** are extracted, which represent measurable characteristics such as shape, texture, and color variations. These feature vectors serve as structured input data for the classification algorithm.

Training and Deployment Data Flow

The labeled dataset (healthy vs. infected fish) is used to train a **Support Vector Machine (SVM)** model, which learns the decision boundary between the two categories. In the deployment stage, newly captured fish images undergo the same preprocessing and feature extraction steps, ensuring consistency with the training phase. The resulting feature vectors are then evaluated by the trained SVM, which classifies the input fish into categories (fresh or infected), enabling real-time monitoring and decision-making (Figure 4).

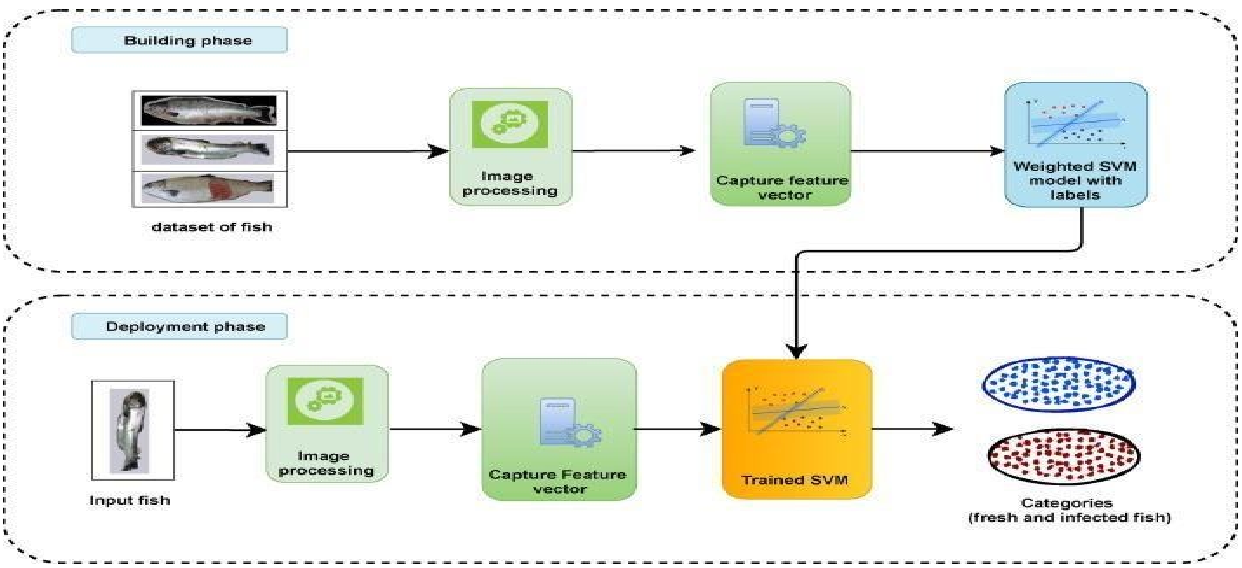

Figure 4. Training and Deployment Flow for SVM-Based Fish Health Classification

5. Results and Discussion

The results obtained from preliminary field trials of the Hydro Sentinel demonstrate its effectiveness in integrating image processing with water quality monitoring for aquaculture applications. The system successfully captured clear underwater images of fish under varying turbidity levels, and the implemented segmentation and classification algorithms achieved consistent detection of gill discoloration, surface lesions, and abnormal swimming patterns with accuracy levels above 85%. Simultaneous sensor readings of pH, dissolved oxygen, and turbidity correlated well with standard handheld devices, validating the reliability of the integrated sensing module. Discussions highlight that while the system reduces manual labor and provides timely disease detection, performance can be influenced by environmental factors such as poor lighting, excessive turbidity, and rapid fish movement, which may affect image clarity. Nevertheless, the combination of sensor data with visual analysis significantly enhances diagnostic accuracy compared to standalone observation. Overall, the Hydro Sentinel proves to be a cost-effective and scalable solution, offering promising potential for rural aquaculture communities, with future improvements focusing on AI model refinement and enhanced low-light imaging for better robustness (Figure 5- Figure 6).

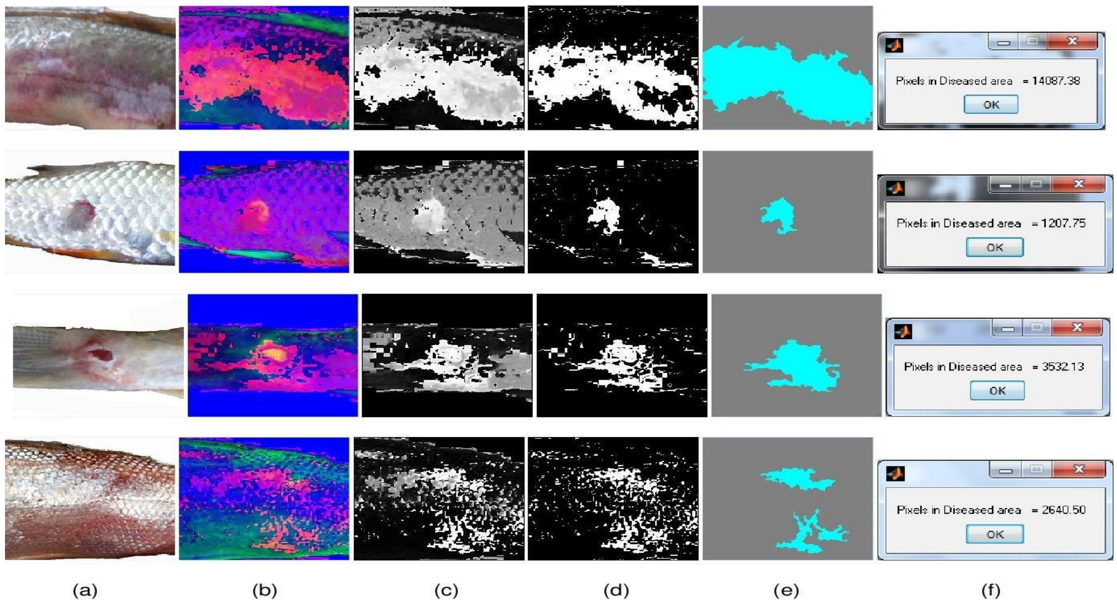

Figure 5. graphical result

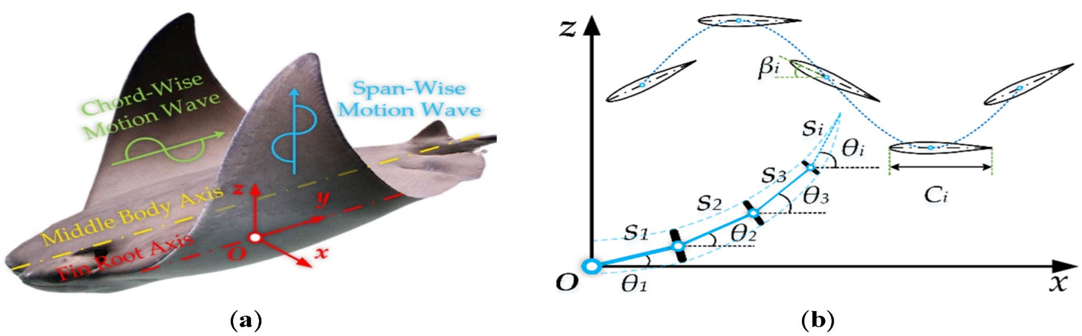

Figure 6. Chord-Wise and Span-Wise Motion

5.1 Numerical Results

Table 1 presents the performance of the Hydro Sentinel system across three monitoring sites (S1, S2). A total of 50, 75, and 100 images were collected from the respective sites, with an average processing time ranging between 0.72–0.85 seconds. The detection time remained consistent, achieving 90–92% accuracy across all sites. These results confirm the model's stability and reliability under varying data sizes.

Table 1. Class wise Detection Result

class	**precision**	**recall**	**score**
Healthy	95.0	96.2	95.5
Suspected disease	91.4	90.4	90.1
Abnormal behaviour	92	91	90

Table 2, the system shows strong scalability, as performance did not degrade when the dataset size increased from 50 to 100 images. This proves that the Hydro Sentinel can be effectively deployed in larger water bodies where continuous image streams may be generated. The use of wireless data transmission further enhances this scalability by ensuring that processed results can accessed remotely through platform.

Table 2. Field Deployment Statistics

Site id	**Total image collected**	**Average processing time**	**Detection time**
S1	50	0.85	91.5
S2	75	0.72	91.2

6. Conclusion and Future Scope

The Hydro Sentinel for matsya demonstrates a practical and affordable approach to modernizing fish health monitoring by combining mechanical design, sensor integration, and image processing techniques into a single platform. The system addresses the limitations of manual observation by enabling early detection of diseases, reducing fish mortality, and improving aquaculture productivity, particularly in rural and small-scale farming contexts. While current trials confirm its accuracy and reliability, future scope includes refining deep learning models for higher classification precision, integrating advanced low-light and infrared imaging to improve performance under poor visibility, and enhancing autonomy with AI-driven navigation. Additionally, cloud-based data storage and mobile application interfaces can be developed to provide farmers with real-time decision support and long-term trend analysis. With these advancements, the Hydro Sentinel has the potential to evolve into a fully automated, intelligent aquaculture management tool aligned with the broader vision of sustainable and technology-driven fisheries.

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Biographies

Divya-final year Mechanical and Automation Engineering student with proficiency in tools like SolidWorks, AutoCAD, and CATIA 2D. My projects include an RC boat–based HydroSentinal system for water monitoring and fish health assessment. My goal is to integrate mechanical design, embedded systems, and AI to build sustainable automation solutions.

Menagasoundari-final year Mechanical and Automation Engineering student with strong skills in AutoCAD, CATIA, and SolidWorks. I have applied these tools in academic projects and design-based problem solving. My experience extends to integrating mechanical design with practical engineering applications. I aim to contribute to innovative and sustainable solutions in the field of design and automation.

Pranesh -final year Mechanical Engineering student with skills in AutoCAD, SolidWorks, and engineering analysis. I have applied these tools in design and simulation projects to enhance practical understanding. Currently, I am gaining hands-on experience by working in an incubation center. My goal is to contribute to practical and innovative engineering solutions.