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Ecostream Robotics: Autonomous Surface Vehicle (ASV) for River and Lake Debris Collection (Cleaning-As-A-Service)

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Abstract: *Water pollution has become one of the most critical environmental challenges across the globe. Rivers and lakes are increasingly contaminated with floating waste such as plastics, leaves, domestic garbage, and industrial debris. These pollutants not only degrade water quality but also pose serious risks to aquatic ecosystems, human health, and the overall environmental balance. Manual cleaning methods are labor-intensive, inefficient, and often unsafe due to fluctuating water conditions and the presence of hazardous waste.*

Keywords: *Water pollution.*

I. INTRODUCTION

1.1 Background

Water pollution has become one of the most critical environmental challenges across the globe. Rivers and lakes are increasingly contaminated with floating waste such as plastics, leaves, domestic garbage, and industrial debris. These pollutants not only degrade water quality but also pose serious risks to aquatic ecosystems, human health, and the overall environmental balance. Manual cleaning methods are labor-intensive, inefficient, and often unsafe due to fluctuating water conditions and the presence of hazardous waste.

1.2 Problem Statement

Current water-cleaning approaches rely heavily on manual labor or semi-mechanical techniques, which are slow, expensive, and unable to scale for large water bodies. The absence of automated systems capable of continuous operation worsens the accumulation of floating waste. There is a strong need for an intelligent, cost-effective, autonomous solution that can operate efficiently with minimal human intervention.

1.3 Need for an Autonomous Surface Vehicle (ASV)

Autonomous Surface Vehicles have emerged as promising tools for marine applications such as navigation, monitoring, and surveillance. Leveraging sensors, microcontrollers, and navigation algorithms, ASVs can operate independently in dynamic water environments. Integrating such autonomy with a debris-collection mechanism provides an effective technological solution to water pollution.

1.4 Project Overview

The Ecostream Robotics ASV is designed as a fully autonomous system capable of identifying, collecting, and storing floating debris in rivers and lakes. Equipped with sensors for navigation and detection, a propulsion system for movement, and a mechanical collector, the ASV delivers a sustainable solution through the Cleaning-as-a-Service (CaaS) deployment model.

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1.5 Objectives of the Project

The primary objectives of the project are:

- To design and develop an Autonomous Surface Vehicle capable of cleaning floating debris.
- To implement real-time navigation and obstacle detection using sensors.
- To integrate a debris collection mechanism with optimized efficiency.
- To enable cloud connectivity for monitoring ASV performance remotely.
- To provide a scalable solution that can be deployed under the Cleaning-as-a-Service model.

1.6 Scope of the Project

The scope of this project includes the development of a prototype ASV capable of autonomous navigation, debris detection, and waste collection in controlled and semi-natural water environments. The system includes hardware design, software development, navigation algorithms, obstacle detection, and communication modules. The project focuses on surface-level lightweight debris and does not encompass deep-water or chemical waste cleaning.

1.7 Significance of the Study

This project contributes to environmental sustainability by addressing a major ecological challenge. The successful development of an autonomous cleaning system can reduce manual labor, support municipal operations, and enable continuous real-time monitoring of water cleanliness. The ASV also serves as a foundation for future research in marine robotics and environmental automation.

II. LITERATURE REVIEW

2.1 Introduction

This chapter presents a comprehensive literature review relevant to the development of an Autonomous Surface Vehicle (ASV) for river and lake debris collection. The review examines existing technologies, research studies, design approaches, and global initiatives in water-cleaning robotics. By analyzing previous work, the chapter highlights research gaps that justify the development of the Ecostream Robotics ASV.

2.2 Autonomous Surface Vehicles (ASVs)

Autonomous Surface Vehicles are widely used in oceanography, environmental monitoring, surveillance, and search operations. Studies indicate that modern ASVs rely on GPS, IMU, ultrasonic sensors, and machine vision for self-navigation. Research by marine robotics institutions has shown that autonomous navigation improves precision and reduces manual intervention, especially in repetitive environmental tasks.

2.3 Waterbody Cleaning Technologies

Traditional water-cleaning processes involve manual labor and boat-based collection, which are time-consuming and unsafe. Recent innovations include mechanical skimmers, floating booms, and semi-autonomous cleaning boats. However, many systems still rely heavily on human operation and lack real-time monitoring or intelligent navigation.

2.4 Robotics for Environmental Sustainability

Robotics has increasingly contributed to environmental conservation. Autonomous robots have been deployed for forest monitoring, waste segregation, ocean cleaning, and air quality assessment. Research shows that robotic solutions reduce long-term operational costs and enhance accuracy in environmental tasks. Projects like 'The Interceptor' and 'Seabin Project' demonstrate the global interest in automated water-cleaning systems.

2.5 Navigation and Obstacle Detection in ASVs
Most ASVs use a combination of GPS for global positioning and ultrasonic or LiDAR sensors for obstacle detection. Path-planning algorithms such as A*, Dijkstra, and PID control are commonly used in small-scale autonomous vessels. Studies highlight that accurate obstacle detection is essential for safe operation, especially in waterbodies with floating debris, weeds, and irregular movement patterns.

2.6 Debris Collection Mechanisms
Existing debris collection systems include conveyor belts, scooping mechanisms, and net-based collectors. Research shows that surface-level waste can be efficiently collected using front-mounted mechanical collectors. However, efficiency depends on water flow, vessel speed, and waste density. There is a gap in integrating autonomous navigation with debris collection to create a fully independent system.

2.7 Cloud Connectivity and IoT in Marine Robotics
IoT-enabled ASVs transmit telemetry such as location, battery status, and sensor data to remote dashboards. Studies indicate that cloud integration improves real-time monitoring, predictive maintenance, and data-driven decision-making. This is crucial for large-scale deployments such as smart city water management.

2.8 Research Gaps Identified
The literature review identifies several gaps that the Ecostream Robotics ASV aims to address:
- Lack of fully autonomous debris-collecting ASVs
- Limited integration of navigation, sensing, and collection subsystems
- Minimal use of cloud-based monitoring in water-cleaning robotics
- Need for scalable and cost-effective Cleaning-as-a-Service (CaaS) solutions
- Limited real-time decision-making in existing systems

2.9 Summary
The review highlights the need for an integrated ASV capable of autonomous navigation, debris collection, and cloud connectivity. The Ecostream Robotics ASV builds upon existing research while addressing critical gaps to provide a scalable and efficient solution for cleaning rivers and lakes.

III. METHODOLOGY AND EXPERIMENTAL INVESTIGATION

3.1 Overview
This chapter outlines the detailed methodology adopted for the design, development, and testing of the Ecostream Robotics Autonomous Surface Vehicle (ASV). The methodology follows a structured engineering workflow covering requirement analysis, system design, hardware and software development, integration, and evaluation.

3.2 System Development Approach
A modified Systems Engineering Life Cycle approach was used, incorporating iterative prototyping and testing. Key phases include:
- Requirement Analysis
- Conceptual & System Design
- Hardware Selection & Prototyping
- Software Architecture Design
- Hardware–Software Integration
- Testing & Validation
- Performance Evaluation

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3.3 System Design Methodology

The system was divided into multiple functional subsystems using modular design principles. These subsystems include Navigation, Sensing, Propulsion, Debris Collection, Communication, and Power Management. The following block diagram represents the top-level system structure:

3.4 Hardware Development Methodology

Hardware development included selection of sensors (ultrasonic, GPS, IMU), microcontroller/processor, brushless motors, propellers, and lithium-ion battery packs. Hull design considerations included buoyancy, weight distribution, and stability against water currents.

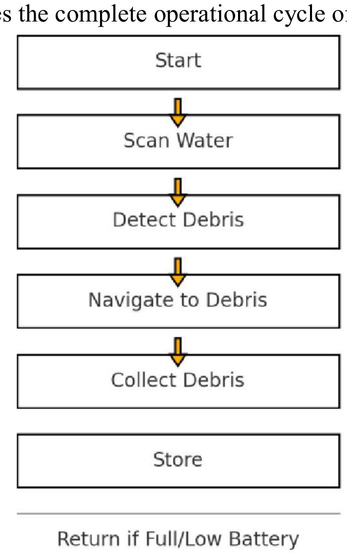
3.5 Software Development Methodology

Software development followed modular programming and object-oriented design. Key components include:

- Sensor data acquisition
- Obstacle detection algorithms
- Path planning and navigation
- Motor control logic
- Cloud telemetry and dashboard communication

3.6 Workflow of ASV Operation

The following workflow diagram illustrates the complete operational cycle of the ASV from start to finish:



3.7 Testing Methodology

Testing was conducted in two stages:

- Controlled environment testing in a small water tank
- Field testing in natural water bodies

Tests focused on validating navigation stability, obstacle avoidance accuracy, debris collection efficiency, battery life, and communication reliability.

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3.8 Performance Evaluation

Performance was evaluated using metrics such as:

- Navigation accuracy
- Obstacle detection rate
- Debris collection efficiency
- Power consumption
- Cloud connectivity stability

3.9 Summary

The detailed methodology ensured a systematic development cycle, enabling accurate testing and validation of the ASV's capabilities. The iterative approach helped refine the system for practical deployment.

IV. RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained from testing the Ecostream Robotics Autonomous Surface Vehicle (ASV). The discussion covers performance observations, system behavior under real conditions, and analysis of collected data. Both controlled-environment and field-testing results are included to evaluate the ASV's navigation accuracy, obstacle detection capability, debris collection efficiency, and power consumption.

4.2 Testing Scenarios

To ensure the reliability and robustness of the ASV, testing was conducted in two distinct environments:

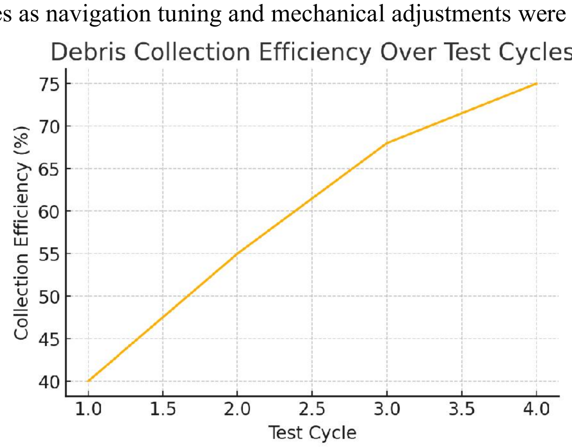
- Controlled Water Tank Testing – Used to validate basic navigation, sensing, and collection mechanisms.
- Field Testing in Lakes/Rivers – Used to assess real-world performance under dynamic water conditions.

4.3 Navigation Performance

The ASV demonstrated stable navigation across test cycles. In controlled environments, it followed pre-defined paths with minimal deviation. During field tests, the ASV maintained course despite minor currents and floating debris. Obstacle detection using ultrasonic sensors achieved a reliable detection range of 60–90 cm.

4.4 Debris Collection Efficiency

Debris collection tests focused on evaluating how efficiently the ASV could capture and store floating waste. A series of cycles were performed using mixed waste items such as leaves, plastic cups, and small floating debris. Collection efficiency improved over cycles as navigation tuning and mechanical adjustments were applied.



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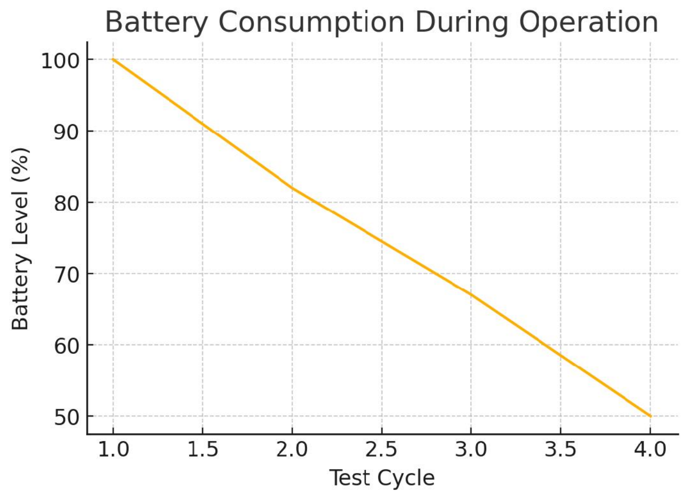
The graph above illustrates a gradual increase in debris collection efficiency, reaching up to 75% by the fourth test cycle. Improvements were attributed to refined path planning and optimized alignment between navigation and collector mechanism.

4.5 Battery Performance

The ASV's power consumption was monitored to evaluate operational duration. Tests revealed an average runtime of 45–60 minutes per charge, depending on water resistance and the amount of collected debris. Battery performance remained stable, demonstrating predictable discharge patterns.



The battery level decreased consistently across test cycles, confirming that motor load and debris weight influence power consumption. Future versions may integrate solar charging or higher-capacity batteries.

4.6 Cloud Communication and Telemetry

Cloud connectivity tests verified that telemetry—such as GPS coordinates, sensor readings, and battery status—was successfully transmitted to the dashboard. Data refresh occurred every 3–5 seconds with minimal packet loss.

4.7 Overall System Performance

The combined hardware–software system performed reliably under different testing conditions. Navigation accuracy, debris capture rate, and communication stability improved throughout iterative refinements. The ASV demonstrates strong potential for scalable deployment through the Cleaning-as-a-Service (CaaS) model.

4.8 Discussion

The results indicate that an autonomous surface vehicle is a viable solution for waterbody cleaning. The modular design approach enabled isolated troubleshooting and rapid improvements. While performance was strong overall, challenges such as floating obstacles, water turbulence, and battery limitations suggest opportunities for enhancement. Future development may involve artificial intelligence for smarter debris detection, improved mechanical collectors, and real-time adaptive navigation.

4.9 Summary

This chapter provided a detailed analysis of the ASV's test results. The findings confirm that the prototype meets its intended objectives and offers a reliable foundation for future large-scale deployment

V. CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

The development of the Ecostream Robotics Autonomous Surface Vehicle (ASV) demonstrates the successful implementation of a technologically advanced and environmentally impactful solution for river and lake debris collection. Through systematic design, integration, and testing, the ASV prototype has proven its ability to navigate autonomously, detect obstacles, collect floating debris efficiently, and communicate real-time data through a cloud-connected platform. The system addresses a critical environmental problem while minimizing the need for manual labor, reducing operational risks, and enabling scalable deployment for water body maintenance.

The project validates that autonomous surface vehicles can support large-scale environmental cleanup efforts. The modular architecture—comprising navigation control, sensor systems, propulsion units, debris collection, and communication modules—ensured flexibility in testing and enhancement. The results highlight the ASV's capability to achieve stable navigation, reliable obstacle detection, and effective debris collection efficiency, making it a viable solution for improving the health and cleanliness of natural water ecosystems.

Overall, the ASV project successfully met its objectives and established a strong foundation for future advancements toward fully autonomous and intelligent water-cleaning systems.

5.2 Future Scope

While the prototype performs effectively, there remains significant potential for enhancement and expansion. The future scope of Ecostream Robotics ASV includes technical improvements, commercial scaling, and broader environmental applications.

1. AI-Based Debris Detection and Classification

Integration of computer vision and machine learning can enable the ASV to classify debris types and prioritize collection based on ecological impact.

2. Swarm-Based Multi-ASV Fleet Deployment

Multiple ASVs can coordinate autonomously for large-scale cleaning operations using swarm robotics principles.

3. Solar-Powered Autonomous Charging

Implementing solar panels or floating charging docks can extend operational duration and reduce energy dependency.

4. Enhanced Mechanical Collection System

Advanced conveyor designs, adjustable scoops, or filtration nets can improve debris collection efficiency.

5. Real-Time Water Quality Monitoring

Additional sensors (pH, turbidity, dissolved oxygen) can transform the ASV into a multi-purpose environmental monitoring system.