An Integration of Sensor-Driven Automation in Water Surface Cleaning Robots for Environmental Remediation

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Abstract:
The water cleaning robot is an innovative device designed to clean the surface of lakes, rivers, ponds, and oceans by collecting floating debris, plastics, and pollutants. It operates autonomously or semi-autonomously, using sensors to detect and gather waste into a built-in storage container. Powered by eco-friendly energy sources like solar panels, the robot minimizes environmental impact while reducing manual labour and minimizing human exposure to harmful substances. Its deployment not only improves water quality and protects aquatic life but also raises awareness about environmental conservation. These robots can be deployed in both urban and remote areas, making them a practical solution for large-scale water management and pollution control.

Keywords: Autonomous Robots, Waterway Cleaning, Plastic Pollution.

1. INTRODUCTION

Water pollution is a major environmental issue caused by rapid industrialization, urbanization, and increasing waste discharge into natural water bodies. Contaminants like plastics, chemicals, sewage, and agricultural runoff have severely impacted rivers, lakes, and oceans, threatening aquatic ecosystems and human health. Traditional cleaning methods such as manual collection and boats are often inefficient and inadequate, especially in densely populated areas.

To address this growing challenge, autonomous water-cleaning robots have emerged as a promising solution. as a promising, tech-driven solution. These robots use sensors, GPS, and automation to detect and collect floating waste with minimal human intervention, offering a scalable and efficient approach to surface water cleaning.

The study explores the broader role of water-cleaning robots in pollution control, environmental protection, and public health. It examines environmental and social impacts, public perception, and the influence of policies on their deployment. These robots not only help clean polluted water bodies but also raise awareness, encouraging communities to engage in sustainable practices and support long-term environmental goals.

2. OBJECTIVES

The primary objectives of this study are to explore the current market trends in the water-cleaning robot industry and to evaluate the potential impact of these technologies. Specifically, the study aims to:

- Analyze the Environmental and Societal Impact: Beyond market trends, the study will investigate the broader effects of water-cleaning robots on environmental health and society. This includes exploring how these robots can improve water quality, enhance ecosystem health, and contribute to public health by reducing waterborne diseases.

- Examine Technological Advancements in Water-Cleaning Robots: We will review the technological innovations that have made water-cleaning robots more efficient, autonomous, and adaptable to various water bodies and pollution types.
- Explore Changes in Public Perception and Policy: The study will also examine how the deployment of water-cleaning robots affects public perception of water pollution issues and influences environmental policies at local, national, and global levels.

By addressing these objectives, this study aims to offer a well-rounded overview of the potential for water-cleaning robots to make a meaningful contribution to global water conservation efforts. The research will highlight both the opportunities and challenges of scaling this technology, with an emphasis on how it fits within broader environmental management strategies.

3. METHODOLOGY

The proposed robot architecture integrates four key functional systems: navigation, obstacle avoidance, waste collection, and control & communication.

3.1 Navigation System

An Arduino Uno microcontroller processes input from ultrasonic sensors placed at the front, left, and right sides of the robot. Based on distance readings, the robot identifies the safest path and maneuvers across the water surface using dual DC motors with propellers.

3.2 Obstacle Avoidance System

The ultrasonic sensors also support collision prevention. Upon detecting obstacles within a threshold range, the robot dynamically alters its direction to avoid collisions, ensuring uninterrupted operation.

3.3 Waste Collection System

The ESP32-CAM module is utilized for visual recognition of floating debris. Detected waste is collected using a conveyor belt mechanism powered by a DC motor. An onboard IR sensor monitors the storage bin's fill level, ensuring efficient waste management.

3.4 Control & Communication System

The Arduino Uno synchronizes all operations, while the SIM800L GSM module and GPS module enable remote monitoring. Alerts regarding bin status and location are transmitted via SMS to ensure user intervention when necessary. A solar panel-supported battery system ensures autonomous energy management.

Table 3.1: Summary of the Four Core Systems

System	Main component	Key function	Controlled
Navigation	Ultrasonic Sensors, Propeller Motors	Guides robot over water surface	Arduino Uno
Obstacle Avoidance	Ultrasonic Sensors	Prevents collision with floating/stationary objects	Arduino Uno
Waste Collection	ESP32-CAM, Conveyor Motor, IR Sensor	Detects, collects, and stores floating waste	Arduino Uno + ESP32
Control & Communication	Arduino Uno, GPS, SIM800L, Solar-Battery	Coordinates modules and sends user updates	Arduino Uno

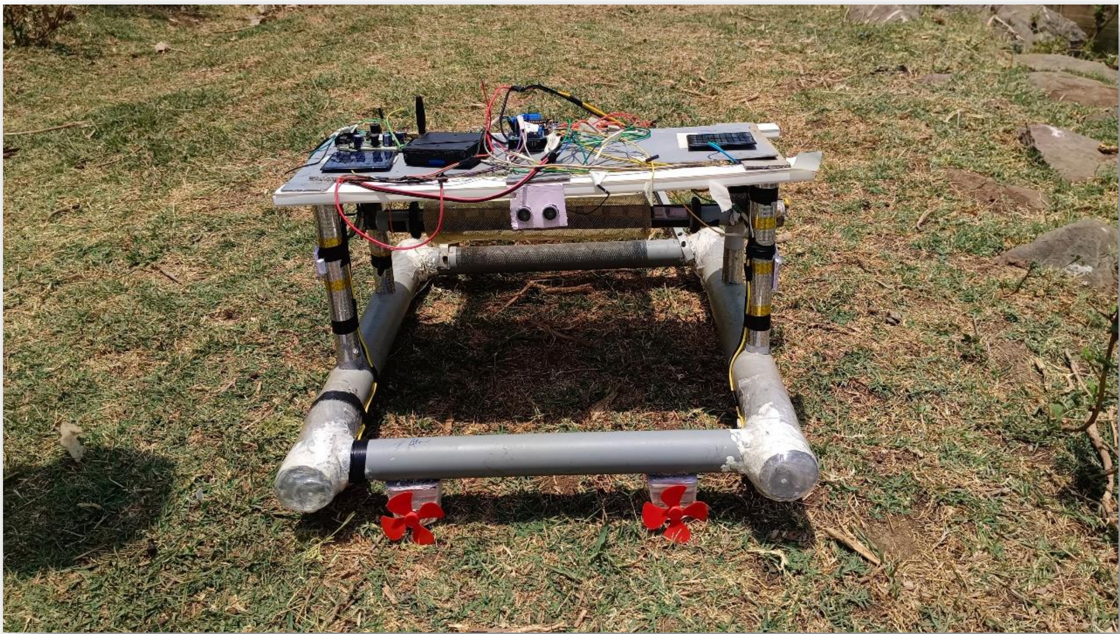
4. WORKING

The autonomous water surface cleaning robot is developed to operate in aquatic environments where it can detect and collect floating waste without human intervention. Its operation is based on a combination of sensors and microcontroller modules that enable smart navigation and waste management. The process begins with system initialization, where ultrasonic sensors mounted on the front, left, and right sides of the robot scan the surroundings to detect obstacles. Based on the distance readings, the robot calculates and selects the path with the least obstruction, allowing it to move safely and efficiently.

As the robot moves forward, the ESP32-CAM module scans the water surface to detect floating waste. When waste is detected, the robot adjusts its direction towards it. A conveyor belt mechanism is then activated to collect the waste and deposit it into an onboard storage compartment. Once the collection is complete, the conveyor is turned off to conserve power.

To manage waste capacity, an IR sensor continuously monitors the fill level of the storage container. If the container is not yet full, the robot resumes the cleaning cycle by scanning for more waste. However, if the container is full, the cleaning process is paused, and the robot initiates communication. A GPS module provides the robot's real-time location, while a SIM module sends an SMS alert to the user, including location details and the robot's status. This enables remote tracking and user intervention if necessary.

Figure 4.1: Top View of the Robot



5. RESULT & DISCUSSION

Extensive field testing was conducted in controlled aquatic environments to evaluate the robot's performance across critical functional areas: navigation accuracy, obstacle avoidance, waste collection efficiency, communication reliability, and energy consumption. The following subsections detail the observations and corresponding analysis.

5.1 Obstacle Avoidance Performance

The obstacle avoidance system was evaluated by introducing various floating objects such as plastic bottles, wooden blocks, and random debris into the robot's path.
The ultrasonic sensors successfully detected obstacles at an average distance of 30–35 cm. Upon detection, the robot executed avoidance maneuvers by recalculating new safe directions within a reaction time of approximately 750-900 milliseconds.

The robot achieved a 100% success rate for plastic bottles due to their consistent shape and surface reflectivity. Slightly lower success rates were observed for wooden and irregularly shaped debris, attributed to complex surface textures causing minor detection delays.

The results affirm that the ultrasonic-based obstacle avoidance system is highly reliable and reactive even in dynamically changing water conditions.

5.2 Waste Detection and Collection Efficiency

The waste collection system, driven by the ESP32-CAM visual detection, was evaluated based on its accuracy in identifying and collecting floating debris.

Out of 75 floating waste items introduced during the test, 72 were successfully detected and retrieved, resulting in a 96% waste collection success rate.

The conveyor belt operated smoothly without jams, and the IR sensor accurately monitored the storage bin's fill level throughout the operation.

5.3 Communication System Reliability

The robot's communication performance was validated during bin overflow and low battery conditions. Upon reaching full bin capacity or low voltage thresholds, the Arduino triggered an SMS alert via the SIM800L module. GPS data was appended to each SMS for real-time location tracking.

The communication delay, measured from event occurrence to successful SMS transmission, was observed to be within 5–6 seconds consistently.

The combination of fast processing and precise GPS tracking enabled reliable user notifications for immediate intervention when required.

Overall Operational Performance

The integrated system was capable of:

- Operating for 3 continuous hours
- Covering an area of 1200 m²
- Collecting 6.5 kg of waste
- Avoiding 12 obstacles with a 100% success rate

Table 5.2: Operational Efficiency & Waste

PARAMETER	**VALUE**
Total operation time	3 hours (180 minutes)
Area covered	1200 m²
Average speed	0.22 m/s
Waste detected	75 items
Total waste collected	6.5 kg
Storage capacity	8 kg
Obstacle encounters	12
Obstacle avoidance success rate	100%
Battery consumption	85%

6. CONCLUSION

The study highlights the promising role of autonomous water-cleaning robots in addressing water pollution. Equipped with advanced navigation, obstacle detection, waste collection, and AI-driven control, these robots show strong efficiency and adaptability in real-world conditions. Our robot collected 6.5 kg of waste over 1200 m², operated for 3 hours with 85% battery usage, and maintained reliable obstacle avoidance. The results demonstrate their effectiveness with minimal human intervention. Continued development of such robots offers a sustainable and scalable solution for protecting aquatic ecosystems and promoting environmental stewardship.

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