IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 6, June 2025
Impact Factor: 7.67

A Review on IoT-Based River Surface Cleaning Robots for Aquatic Waste Management

Sakshi Vijay Awari[1], Sudarshan Vijay Pulate[2], Saurabh Dattu Gadakh[3], Prof. Bhoir. N. V.[4]
[1,2,3,4]Department of E&TC Engineering
Vidyaniketan College of Engineering, Bota, A.Nagar, MH

Abstract: *This paper reviews the current technological advancements in river surface cleaning robots that utilize IoT, automation, and remote control technologies for aquatic waste management. With increasing pollution levels in water bodies, there is an urgent need for efficient, safe, and scalable solutions for cleaning operations. This review highlights various designs, control mechanisms, communication protocols, and mechanical systems employed in recent developments. It also discusses challenges, future directions, and environmental significance of adopting such robotic solutions for sustainable water resource management.*

Keywords: River Cleaning Robot, IoT, Waste Collection, Water Pollution, Remote Control

I. INTRODUCTION

Water bodies such as rivers, lakes, and canals serve as essential lifelines for ecological balance, human consumption, agriculture, transportation, and recreation. However, due to rapid urbanization, industrialization, and unsustainable waste disposal practices, these water bodies are increasingly being polluted with floating debris, plastics, and other non-biodegradable materials. The accumulation of such pollutants not only affects aquatic biodiversity but also poses significant threats to public health, economic activities, and the overall environment. Addressing this growing challenge requires innovative, efficient, and sustainable solutions that can minimize human intervention while maximizing the cleaning efficiency of these polluted water surfaces.

Traditional methods of cleaning river surfaces typically involve manual labor, which is not only time-consuming and labor-intensive but also exposes workers to hazardous conditions, including strong water currents, pathogens, and harmful chemicals. Moreover, the manual collection of waste is often inefficient for large-scale or continuous cleaning requirements. Mechanical boats and large barges have been employed in some regions, but their high operational and maintenance costs, as well as limited accessibility to narrow or shallow areas, reduce their practicality and scalability. Thus, there is a clear need for technological solutions that can overcome the limitations of both manual and conventional mechanical cleaning systems.

Recent advancements in automation, robotics, wireless communication, and the Internet of Things (IoT) have opened new avenues for the development of smart river cleaning systems. IoT-based remote-controlled river surface cleaning robots present a highly effective solution by combining real-time monitoring, wireless control, and autonomous debris collection capabilities. These robots can be operated remotely using mobile applications, reducing the need for human presence in hazardous environments, and allowing for more precise and efficient cleaning operations. Additionally, their modular design makes them adaptable to various water bodies and pollution levels.

The integration of microcontrollers such as ESP32, motor drivers like L298N, geared DC motors, and conveyor belt mechanisms allows these robots to effectively collect floating waste while maintaining stable movement on the water surface. The ESP32 microcontroller, in particular, provides built-in Wi-Fi capabilities that enable seamless communication with user interfaces such as the Blynk app, allowing operators to control the robot from a safe distance. This level of control and flexibility significantly enhances operational safety and efficiency, particularly in areas where traditional cleaning methods may be impractical.

In addition to addressing immediate waste collection needs, these robots can also be equipped with various sensors and data logging capabilities to monitor water quality parameters such as pH, temperature, turbidity, and dissolved oxygen levels. By incorporating environmental monitoring features, these systems can serve a dual purpose of cleaning and continuously assessing the health of the water body, thereby contributing valuable data for environmental management and policymaking. Such multi-functional systems align with global sustainability goals and promote responsible water resource management.

Despite the promising potential of IoT-based river cleaning robots, several challenges remain that must be addressed to ensure their widespread adoption. Issues such as power management for prolonged operations, obstacle avoidance in dynamic water environments, wireless connectivity stability, and long-term maintenance need to be thoroughly researched and resolved. Moreover, the economic feasibility and scalability of deploying multiple robots across larger geographic areas also warrant careful consideration. Continued research and development efforts are essential to refine these systems, enhance their capabilities, and address the technical, operational, and economic barriers that currently exist.

This review paper aims to provide a comprehensive overview of the existing technologies, design approaches, hardware and software components, operational advantages, challenges, and future directions in the field of IoT-based river surface cleaning robots. By examining the state-of-the-art developments and identifying current limitations, this paper seeks to contribute to ongoing research efforts aimed at developing practical, efficient, and sustainable solutions for water pollution control.

PROBLEM STATEMENT

The increasing accumulation of floating waste in rivers and water bodies poses severe environmental, health, and ecological threats. Traditional manual and mechanical cleaning methods are inefficient, labor-intensive, and often unsafe. There is a critical need for an automated, safe, and cost-effective solution to clean river surfaces efficiently while minimizing human intervention.

II. LITERATURE SURVEY

1. Vidhya Sagar N., Yogesh S. V., Vishwa S., Dr. Binu D. (2021). "River Surface Monitoring and Cleaning Robot."

This paper presents a stationary autonomous river surface cleaning robot powered by solar energy. It is designed to collect plastic waste from rivers before it reaches the ocean. The system uses a conveyor belt to pick up floating debris, and sensors are integrated for real-time monitoring of water quality. One limitation of this system is that it is stationary, and its effectiveness is dependent on the flow of the river and the strategic placement of the robot. The paper does not address how the robot would handle varying debris loads or operate in different water conditions.

2. Aman George Sebastian, Madhav Devnarayan, Bachu James, Abhishek Thomas (2024). "Water Surface Cleaning Robot."

This paper introduces a water surface cleaning robot designed to clean rivers and water bodies autonomously using a conveyor belt mechanism. The robot collects floating waste and conveys it into a storage compartment using the belt. The project emphasizes autonomous operation and real-time visuals via a camera for waste detection. However, the study focuses more on design and early-stage development, and lacks in-depth analysis of performance or real-world testing under different environmental conditions. Additionally, the paper highlights a future vision for handling large-scale debris but does not offer concrete solutions for certain challenges like underwater waste collection.

3. Kshitija A. Ingle, Akash G. Bhatkar, Rahul S. Tarmale, Tejashri D. Ingle, Mohan S. Bawaskar, Mangesh J. Nemade (2020). "River Cleaning Robot Using Solar Power."

This paper proposes a solar-powered river cleaning robot designed to collect floating waste using a conveyor belt. The robot uses DC motors and is controlled via Bluetooth. The conveyor collects waste and transfers it into a bin for disposal. The focus on solar energy provides a sustainable energy source for long-term operation. However, the design lacks in terms of addressing scalability and the ability to handle different types of waste across varying water conditions. The paper suggests the need for further modifications for larger water bodies and deeper rivers.

III. EXISTING TECHNOLOGIES

A. Manual Cleaning Methods

Manual cleaning methods are the most basic and widely used approach for removing waste from the surface of rivers and water bodies. This process typically involves deploying teams of workers equipped with nets, boats, and protective gear to manually collect floating debris such as plastic bottles, leaves, and other solid waste. While this method has the advantage of being low-cost in terms of initial equipment investment, it suffers from several significant drawbacks. Manual cleaning is highly labor-intensive, time-consuming, and inefficient, especially for large-scale operations or heavily polluted water bodies. Moreover, workers are exposed to various health hazards such as waterborne diseases, toxic chemicals, and physical injuries caused by unstable surfaces, strong currents, or submerged obstacles. In rapidly urbanizing areas with large rivers, manual methods often fail to keep up with the rate at which waste accumulates, rendering them ineffective for long-term water management solutions.

B. Mechanical Cleaning Boats

Mechanical cleaning boats have been introduced in some regions to overcome the limitations of manual cleaning. These boats are typically equipped with mechanized arms, conveyors, and storage bins that allow them to collect waste more efficiently and with less manual labor. They can cover larger areas compared to manual cleaning teams and can operate for extended periods. However, mechanical cleaning boats come with high capital and maintenance costs, limiting their adoption primarily to government agencies or large organizations. Additionally, their large size and design make them unsuitable for narrow, shallow, or difficult-to-navigate water bodies such as small rivers, streams, and urban canals. The complexity of operating and maintaining these machines, along with fuel consumption and environmental impact, further restrict their practical usage for widespread or continuous operation.

C. Autonomous Surface Vehicles (ASV)

Autonomous Surface Vehicles (ASVs) represent a more advanced approach to water surface cleaning. These robotic platforms utilize a variety of sensors such as LiDAR, sonar, cameras, and GPS modules, combined with artificial intelligence (AI) algorithms to autonomously navigate water bodies, avoid obstacles, and identify debris for collection. ASVs are capable of operating without constant human supervision, making them well-suited for continuous monitoring and cleaning tasks. They can also be programmed to optimize their cleaning paths, thus increasing efficiency and conserving energy. However, ASVs often involve high development and operational costs, sophisticated design requirements, and complex software systems. The deployment of ASVs may also face regulatory hurdles related to autonomous navigation in public waterways. Furthermore, the high level of technical expertise required for their operation and maintenance makes them less accessible for many communities or smaller organizations.

D. Semi-Autonomous Robots

Semi-autonomous robots offer a balanced alternative by integrating IoT-based control systems with manual oversight and intervention capabilities. These robots are typically equipped with wireless communication modules such as Wi-Fi or Bluetooth, microcontrollers, motor drivers, and simple sensor arrays for basic navigation and obstacle detection. Operators can remotely control these robots through mobile or web-based applications, allowing for real-time monitoring and command input. The semi-autonomous nature of these robots provides the flexibility to navigate complex environments while still benefiting from human decision-making for more challenging tasks. They are generally more affordable and easier to build and maintain than fully autonomous systems, making them suitable for smaller water bodies, municipal use, and pilot projects. Additionally, their modular design allows for customization and scalability based on the specific requirements of different cleaning operations.

IV. PROPOSED SYSTEM

The proposed system aims to develop a semi-autonomous, remote-controlled river surface cleaning robot that utilizes IoT-based technologies for efficient waste collection from water bodies. The design integrates a combination of mechanical, electrical, and communication components that work together to provide a reliable, safe, and cost-effective solution to water surface pollution.

A. System Architecture

The system is composed of multiple subsystems: the control system, propulsion system, debris collection mechanism, power supply unit, and user interface. All subsystems are integrated into a floating platform designed to remain stable on the water surface while navigating and collecting debris.

B. Control System

The control system serves as the brain of the robot and is built around the ESP32 microcontroller. The ESP32 is selected due to its built-in Wi-Fi capabilities, low power consumption, and ease of programming using the Arduino IDE. The microcontroller receives commands from the user via a mobile application (such as Blynk), processes these commands, and generates appropriate signals to control the motors and sensors. It is also responsible for monitoring system status and managing communication between all hardware components.

C. Propulsion System

The propulsion system consists of two geared DC motors, which are connected to the left and right sides of the floating platform. These motors are controlled through an L298N motor driver, which allows for precise control over the robot's movement, including forward, backward, left, and right navigation. The motor speed and direction are managed using Pulse Width Modulation (PWM) signals generated by the ESP32 microcontroller. This configuration allows the operator to remotely control the robot's movements with fine precision, making it easier to navigate around obstacles and concentrate on areas with high waste accumulation.

D. Debris Collection Mechanism

A key feature of the proposed system is the conveyor belt-based debris collection mechanism. As the robot moves across the water surface, the conveyor belt, driven by a separate DC motor, continuously scoops floating debris such as plastic bottles, leaves, and other waste into an onboard collection bin. The conveyor system ensures continuous and automated waste collection, minimizing the need for human intervention during operation. The conveyor motor is also controlled via a separate L298N motor driver connected to the ESP32, allowing the operator to start or stop the collection process as needed.

E. Power Supply System

The entire system is powered by a 12V Li-ion battery, which provides sufficient energy to operate the motors, control system, and communication modules. Since some components, such as the ESP32 and motor driver logic circuits, require 5V for safe operation, a 7805 voltage regulator is used to step down the 12V supply. This ensures stable and reliable voltage levels for sensitive components while maintaining system safety.

F. Communication and User Interface

The proposed system incorporates IoT-based wireless communication using the ESP32's built-in Wi-Fi module. The robot can connect to a local Wi-Fi network and be controlled remotely via a mobile application such as Blynk. The app provides a user-friendly interface that allows the operator to send movement commands, control the conveyor mechanism, and monitor operational parameters like battery status and connectivity. This remote-control capability allows for flexible operation even when the operator is not physically present at the cleaning site.

G. Safety and Maintenance

The design includes safety features such as overload protection on the motor drivers and voltage regulation to prevent component damage. Regular maintenance involves inspecting the motors, conveyor system, battery, and electrical connections to ensure long-term operational stability. The modular design makes repairs and upgrades easy, further enhancing system longevity.

H. Advantages of the Proposed System

- **Cost-Effective:** Uses affordable and easily available components.
- **Remote Operation:** Minimizes human exposure to hazardous environments.
- **Efficient Collection:** Continuous waste collection using the conveyor mechanism.
- **Scalable Design:** Can be adapted for different sizes of water bodies.

- **User-Friendly:** Simple interface for remote operation via mobile app.

Hardware Components

ESP32/ESP8266 Microcontrollers

The ESP32 and ESP8266 microcontrollers serve as the core processing and control units of the system. Both modules offer built-in Wi-Fi capabilities, allowing for seamless communication between the robot and remote control applications. The ESP32 provides more processing power, additional GPIO pins, and enhanced features compared to the ESP8266, making it ideal for more complex control tasks, multiple motor controls, and sensor integration.

L298N Motor Drivers

L298N motor drivers act as intermediaries between the microcontroller and the DC motors, providing the necessary current and voltage required for motor operation. They facilitate the control of motor direction and speed through H-Bridge configurations and Pulse Width Modulation (PWM) signals. This component ensures stable operation and allows precise maneuvering of the robot across the water surface.

Geared DC Motors

Geared DC motors are responsible for the propulsion of the robot and the operation of the conveyor belt system. The gears reduce the speed of the motor while increasing torque, allowing for smooth and controlled movement. These motors ensure sufficient force to navigate water currents and drive the debris collection system efficiently.

Conveyor Belt Systems

The conveyor belt mechanism is central to the waste collection process. As the robot moves, the conveyor belt continuously collects floating waste and transfers it into an onboard collection bin. The simple, robust design of the conveyor system ensures continuous operation with minimal mechanical complexity.

Li-ion Battery Packs

Li-ion battery packs serve as the primary power source for the robot, offering a balance between high energy density, lightweight design, and rechargeable capabilities. The battery packs are capable of powering both the propulsion system and the control electronics for extended periods, ensuring uninterrupted cleaning operations.

Ultrasonic/IR Sensors for Obstacle Detection

Ultrasonic and infrared sensors are integrated to provide obstacle detection capabilities. These sensors allow the robot to sense nearby objects, prevent collisions, and safely navigate around obstacles such as floating logs, buoys, or other debris in the water.

Software Components

Arduino IDE (Programming Environment)

The Arduino Integrated Development Environment (IDE) is used for writing, compiling, and uploading control algorithms to the ESP32/ESP8266 microcontrollers. The Arduino platform offers extensive library support and a user-friendly interface, making it accessible for both novice and advanced developers.

Custom IoT Apps for Remote Monitoring

The Blynk App provides a simple, customizable interface for remote monitoring and control of the cleaning robot. Users can remotely operate the robot’s movement, monitor its operational status, and control the debris collection system. Custom IoT apps can also be developed to tailor the user interface to specific project needs.

Embedded C / Python for Control Algorithms

Control algorithms for the robot are typically developed in Embedded C (commonly used with Arduino) or Python. These algorithms manage motor control, obstacle avoidance, data acquisition, and communication processes, ensuring the robot operates reliably and efficiently.

Cloud Platforms for Data Storage and Analysis

Cloud-based platforms can be integrated for real-time data logging, storage, and analysis. Operational parameters, cleaning progress, and environmental data can be stored on cloud servers, allowing for remote monitoring, performance analysis, and long-term data management that can support environmental studies and policy-making.

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ADVANTAGES AND APPLICATIONS

The proposed river surface cleaning robot was tested under various operational conditions to evaluate its performance, efficiency, and reliability. The system successfully demonstrated stable navigation, effective debris collection, and smooth remote-control operation via the Wi-Fi-based mobile application.

A. Advantages

Cost-Effective Solution:

The proposed system uses easily available and low-cost components such as ESP32 microcontrollers, L298N motor drivers, and DC motors, making it affordable for municipalities, local authorities, and organizations even with limited budgets.

Remote and Safe Operation:

By employing IoT-based remote control through mobile applications, the robot reduces the need for human involvement in hazardous environments, minimizing health risks for workers and ensuring safe cleaning operations.

Eco-Friendly Design:

The electric-powered system ensures minimal environmental impact compared to fuel-powered mechanical boats. Its efficient energy consumption allows longer operation times without contributing to further pollution.

Efficient Waste Collection:

The conveyor belt mechanism allows continuous and automated collection of floating waste, increasing the amount of waste collected per cleaning session compared to manual or traditional methods.

Scalable and Adaptable:

The modular design allows for easy scaling and customization to fit different sizes of rivers, lakes, canals, and ponds. Additional sensors or functionalities can be integrated based on specific cleaning needs.

B. Applications

River and Canal Cleaning:

Ideal for cleaning rivers, canals, and small water bodies where manual cleaning is challenging and mechanical boats cannot operate efficiently.

Lakes and Urban Water Bodies:

Useful for maintaining the cleanliness of lakes, reservoirs, and urban ponds where floating debris frequently accumulates due to human activity.

Industrial and Commercial Facilities:

Applicable for water treatment plants, industrial discharge sites, and commercial waterfronts to manage waste accumulation effectively.

Flood Control Channels and Drainage Systems:

Can assist in keeping flood control channels and drainage systems clear of debris, preventing blockages that contribute to urban flooding.

Support for Environmental Conservation Programs:

The robot can be integrated into government and NGO-led environmental conservation programs focusing on water body restoration, biodiversity protection, and public health initiatives.

V. CONCLUSION

The proposed remote-controlled river surface cleaning robot offers a practical, cost-effective, and efficient solution to the growing problem of water pollution. By integrating IoT technology, simple mechanical systems, and user-friendly interfaces, the system enables safe and continuous waste removal from various water bodies. Its modular design, low operational cost, and adaptability make it suitable for wide-scale deployment, contributing significantly to environmental conservation and public health protection.

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