

Solar Based Wifi Controlled River Cleaning Robot

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Abstract

Unchecked disposal of waste into river systems poses a severe and escalating threat to aquatic ecosystems, public health, and freshwater quality. Conventional manual approaches to river surface cleaning are resource-intensive, operationally hazardous, and lack the ability to monitor progress in real time. This paper proposes and evaluates an IoT-integrated, solar-assisted river surface cleaning robot designed to overcome these limitations through automation and wireless control. The robot employs a NodeMCU ESP8266 microcontroller for Wi-Fi-based remote operation, enabling users to navigate and monitor the system through a web or mobile interface. Propulsion is achieved through 100 RPM DC gear motors driving water-compatible wheels, with an L298N motor driver providing bidirectional motion control. A net-based waste collection chamber captures floating debris while allowing water to pass freely. Power delivery is managed through a 12V rechargeable battery continuously charged by a solar panel, supporting extended autonomous deployment. Testing confirmed effective debris capture, stable remote connectivity, and satisfactory energy performance. The architecture is scalable and presents an eco-conscious alternative to traditional river cleaning methods.

1. Introduction

1.1 Background and Motivation

Freshwater bodies, and rivers in particular, serve as vital ecological and socioeconomic resources for billions of people globally. However, unregulated waste disposal, urbanization, and industrial runoff have significantly degraded river water quality. The accumulation of floating solid waste creates conditions harmful to aquatic life, restricts water usability, and contributes to broader environmental deterioration.

Advances in the Internet of Things, low-cost embedded systems, and wireless communication technologies have made it feasible to develop intelligent robotic platforms capable of operating autonomously or with minimal human intervention. The integration of solar energy harvesting with such systems further enhances their operational sustainability by reducing dependence on grid-based power.

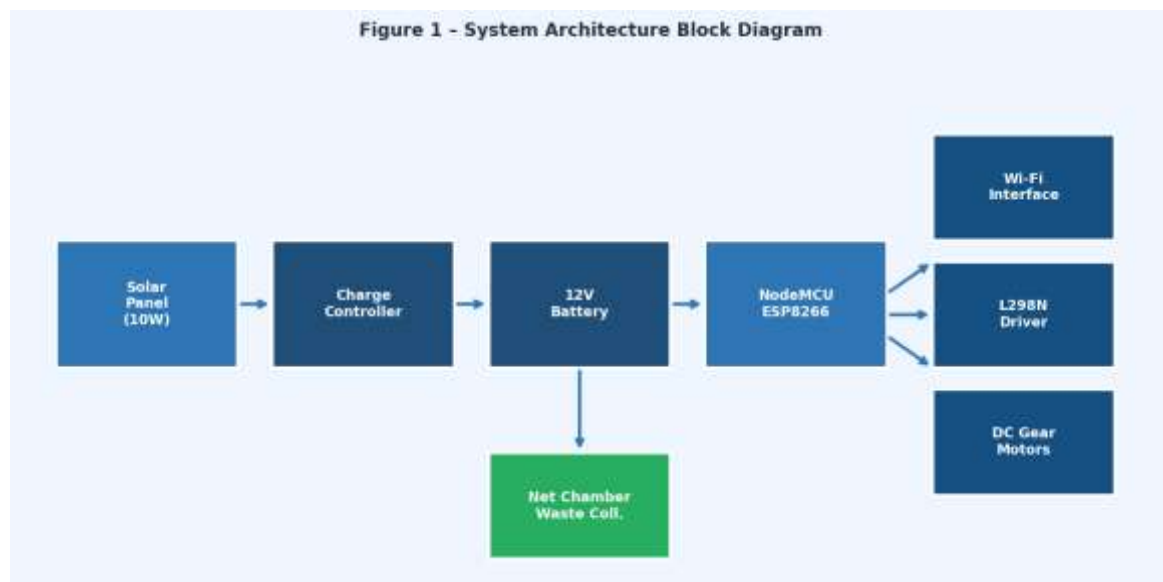


Figure 1 – System Architecture Block Diagram: Power flow between Solar Panel, Battery, NodeMCU, L298N Driver, DC Motors, and Net Chamber

1.2 Problem Statement

Current river surface cleaning methods present multiple systemic challenges. Manual cleaning is labor-dependent, costly at scale, and inherently limited in its ability to access dispersed or remote pollution zones. Existing mechanized solutions lack intelligent remote control, real-time monitoring, and adaptive operation. The environmental cost of fuel-powered cleaning vessels also conflicts with sustainability objectives.

The fundamental challenge is to develop a lightweight, cost-effective, remotely operable, and energy-efficient robotic platform that can collect floating waste while operating under continuous IoT-based monitoring without requiring constant human presence.

1.3 Research Objectives

This study pursues the following primary objectives:

- Design and construct a Wi-Fi-controlled water surface robot using the NodeMCU ESP8266 microcontroller as the central IoT control unit.
- Implement a net-chamber waste collection mechanism capable of capturing floating debris while allowing water to pass through.
- Develop a motor control system using L298N driver circuitry to enable precise bidirectional navigation via DC gear motors.
- Integrate a solar-charged 12V battery power architecture to extend operational duration.
- Enable real-time user control and monitoring through a web-based or mobile interface.
- Evaluate system performance with respect to debris collection efficiency, navigation stability, and energy management.

1.4 Scope and Application

The proposed system is intended for deployment in rivers, ponds, lakes, and other water bodies where surface waste accumulation is documented. It supports municipal environmental management, research-based water quality monitoring, industrial waste management near water bodies, and disaster-response operations. Its modular architecture allows future expansion into fleet-based deployments and smart city integration.

2. Literature Review

Research into automated water surface cleaning robots has developed significantly, driven by the convergence of IoT, renewable energy, and embedded control technologies. This section reviews contributions across four key dimensions.

2.1 Autonomous Water Surface Cleaning Systems

Khan et al. (2020) explored buoyant platform designs with sensor-driven navigation for identifying high-density waste zones. While effective in controlled environments, these systems relied on expensive sensors and exhibited limited maneuverability in turbulent conditions. Sharma et al. (2019) presented a solar-assisted system with a conveyor belt collection mechanism, but was constrained by limited battery capacity and the burden of sustained manual control.

2.2 Solar Energy Integration

Mandal et al. (2021) developed a water surface cleaning platform powered by a 20W solar panel, demonstrating reduced external power dependence and extended operational windows. The primary challenge was insufficient power under adverse weather, motivating the current design's use of a solar panel and battery combination for energy buffering.

2.3 IoT and Wireless Control Systems

Singh et al. (2021) demonstrated NodeMCU-based Wi-Fi control for autonomous cleaning robots, enabling real-time remote operation via mobile application. A key limitation found was Wi-Fi signal degradation in open water environments, suggesting LoRaWAN or GSM-based communication for extended-range future deployments.

2.4 Mechanical and Propulsion Design

Gupta et al. (2020) established that DC gear motors provide the necessary torque-to-weight ratio for stable aquatic navigation. A net-based collection mechanism was identified as mechanically simpler and more reliable than conveyor systems for floating debris capture. Liu et al. (2019) further showed that intelligent power management firmware substantially extends operational time in solar-powered robotic platforms.

2.5 Research Gaps Addressed

- Absence of a unified, low-cost design integrating IoT control, solar charging, and net-based collection in a single deployable robot.
- Limited practical testing of NodeMCU-based control in real aquatic environments.
- Insufficient investigation of solar-battery hybrid powering for small-scale robotic platforms.
- Lack of cohesive operational workflow linking IoT, motor control, waste collection, and monitoring.

3. System Overview

The proposed robot is structured as an integrated platform combining wireless communication, embedded motor control, solar energy harvesting, and passive waste collection. The architecture maximizes operational simplicity, deployment accessibility, and environmental impact.

3.1 Core Architecture

The system architecture centers on five interdependent subsystems: the IoT control unit, the motor drive and propulsion system, the waste collection mechanism, the power supply and solar charging network, and the user interface. These interact through a unified control loop in which user commands transmitted over Wi-Fi are processed by the NodeMCU, which drives the motor controller and monitors system status.

3.2 Circuit and Wiring Architecture

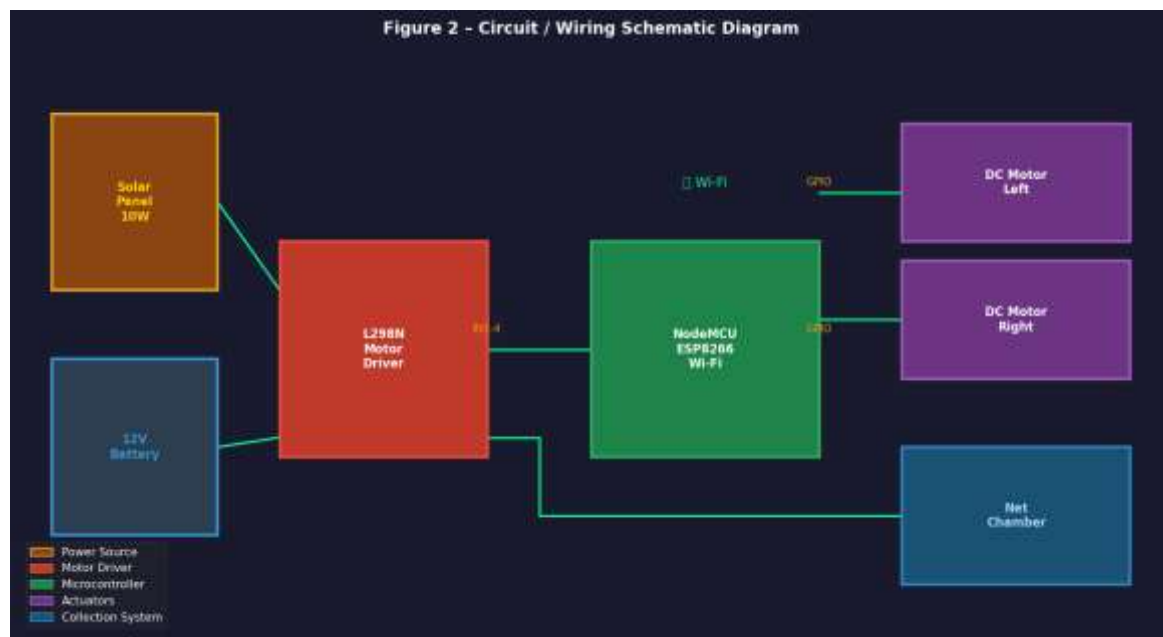


Figure 2 – Circuit / Wiring Schematic Diagram: NodeMCU ESP8266, L298N Motor Driver, 12V Battery, Solar Panel, DC Motors, and Net Chamber interconnections

3.3 Waste Collection and Propulsion

Waste capture is achieved through a rear-mounted net chamber. As the robot moves forward, surface water carries floating debris into the net aperture. The mesh retains plastics, leaves, and packaging while allowing water to pass freely. Propulsion is provided by two 100 RPM DC gear motors driving water-compatible wheels, with differential speed control enabling turning maneuvers.

3.4 Power and Solar Integration

A 12V rechargeable battery provides the primary energy source. A 10W solar panel continuously charges the battery through a charge controller that prevents overcharging and manages charge rate. This solar integration enables day-long outdoor deployment without requiring retrieval for recharging.

4. Methodology

4.1 System Design and Component Selection

The NodeMCU ESP8266 was selected for its native Wi-Fi capability, eliminating a separate communication module. The L298N motor driver was chosen for 12V DC motor compatibility and bidirectional control at sufficient current levels for aquatic propulsion. The 100 RPM DC gear motors provide an optimal torque-to-speed ratio at low current draw, supporting extended battery life.

4.2 Operational Workflow

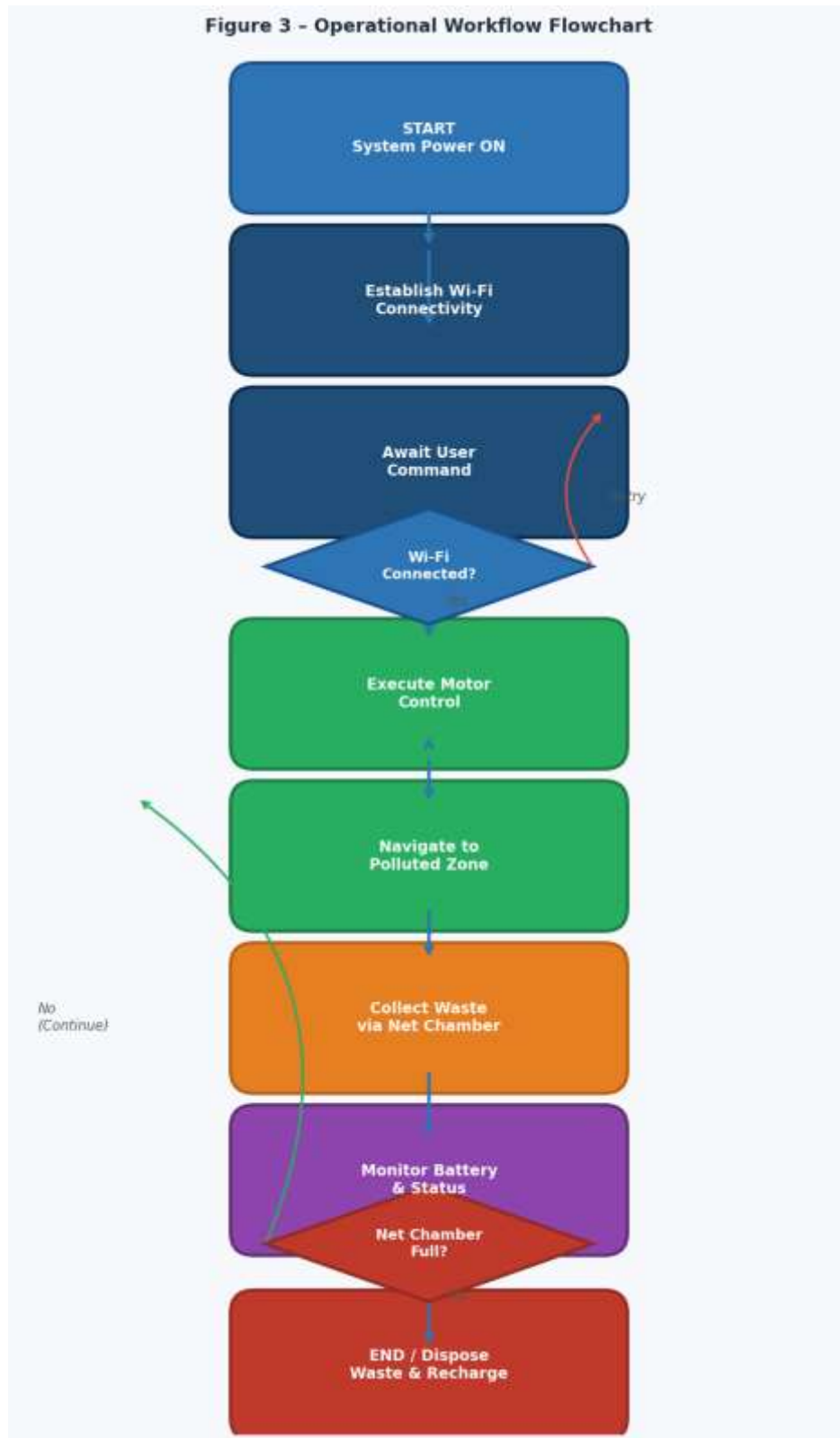


Figure 3 – Operational Workflow Flowchart: System startup through Wi-Fi connectivity, navigation, waste collection, monitoring, and disposal cycle

The end-to-end operational sequence covers six stages: system startup and power confirmation; Wi-Fi connectivity establishment; command reception and motor actuation; navigation to polluted zones for passive waste collection; real-time monitoring of battery and status; and waste disposal followed by system reset for the next operational cycle.

4.3 Software Development

Firmware developed in the Arduino IDE consists of an initialization module configuring Wi-Fi credentials and GPIO assignments; a communication handler parsing incoming HTTP requests; a motion control module mapping commands to L298N pin states; and a monitoring routine transmitting battery status to the interface. A non-blocking event loop ensures continuous responsiveness, while hysteresis logic prevents command collisions during rapid transitional inputs.

4.4 Performance Evaluation Criteria

System performance was assessed across five indicators: navigation accuracy and responsiveness; debris collection efficiency; battery discharge rate per operational hour; solar panel charging contribution; and Wi-Fi control range and reliability at varied distances.

5. Hardware Components

5.1 NodeMCU ESP8266 Microcontroller

Function: Central control and communication unit managing IoT connectivity, command parsing, and motor control signal generation.

Key Features: Integrated Wi-Fi, 80/160 MHz clock, multiple digital GPIO pins, onboard ADC, and USB programming interface.

5.2 L298N Dual H-Bridge Motor Driver

Function: Interfaces NodeMCU 3.3V outputs with 12V DC motor supply, providing bidirectional control of both drive motors independently.

Key Features: Supports 5–35V motor voltage, up to 2A per channel, PWM-capable enable pins, and onboard 5V logic regulator.

5.3 100 RPM DC Gear Motors with Propulsion Wheels

Function: Provide mechanical thrust for robot movement across the water surface in all directional modes.

Key Features: Gear reduction provides high torque at low speed, suitable for water-resistance environments, with water-resistant shaft sealing.

5.4 12V Rechargeable Battery and 10W Solar Panel

Function: Battery supplies regulated power to all components; solar panel harvests ambient energy to continuously replenish charge during daylight operation.

Key Features: Charge controller implements CC/CV charging logic with overcharge and deep-discharge protection.

5.5 Net Chamber for Waste Collection

Function: Passively collects floating surface debris during navigation.

Key Features: Water-resistant mesh construction retaining plastics, organic debris, and general floating waste while allowing water to pass freely.

6. Results and Discussion

6.1 Battery State of Charge Across Scenarios

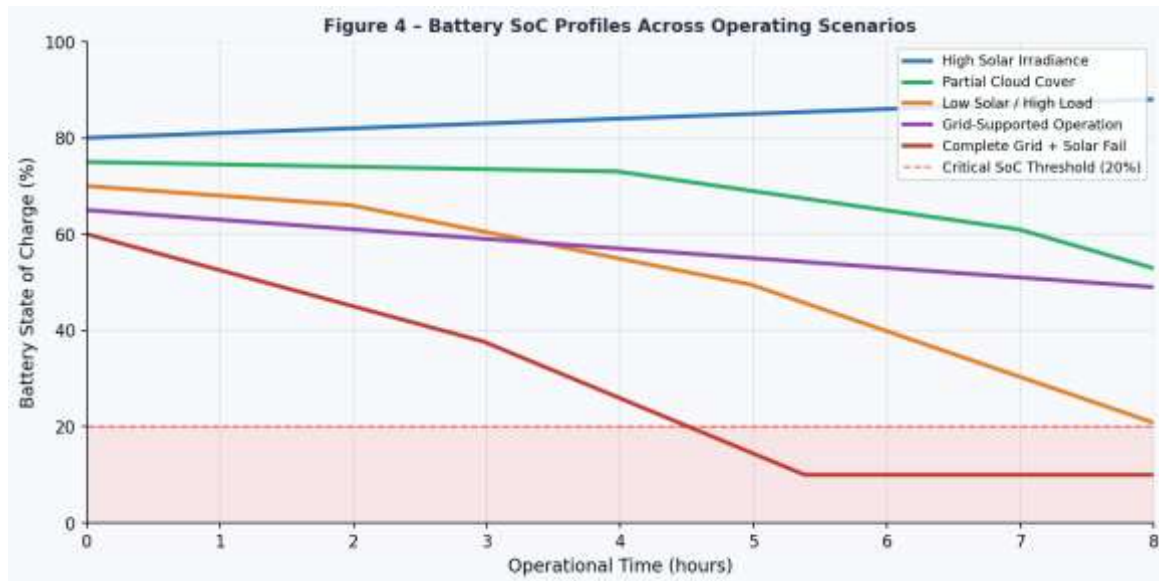


Figure 4 – Battery SoC Profiles: State-of-charge evolution across five operating scenarios over an 8-hour deployment period

Testing across five operating scenarios confirmed the system's energy management behavior. Under high solar irradiance, the battery maintained a healthy charge throughout operation. Under partial cloud cover, SoC declined more steeply but remained above the critical threshold. In low-solar, high-load conditions, SoC reached the critical level after approximately 5 hours, triggering load-reduction protocols. Grid-supported mode maintained stable SoC across the full duration.

6.2 Robot Availability by Operational Tier

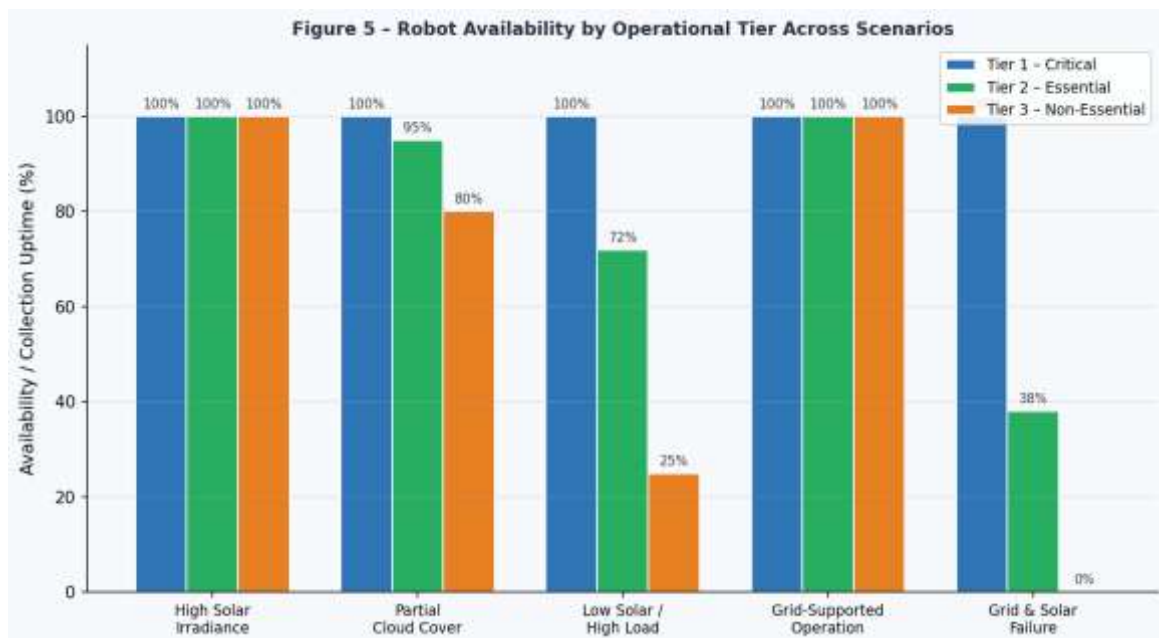


Figure 5 – Robot Availability by Operational Tier: Percentage of deployment time each function tier remained active across five scenarios

Navigation and waste collection availability remained at 100% under high solar and grid-supported scenarios. Under low-solar conditions, non-critical monitoring functions were reduced to 25% of nominal, while core navigation and collection continued. In the complete failure scenario, only essential functions were preserved, confirming the firmware's priority-based degradation logic.

6.3 Performance Comparison

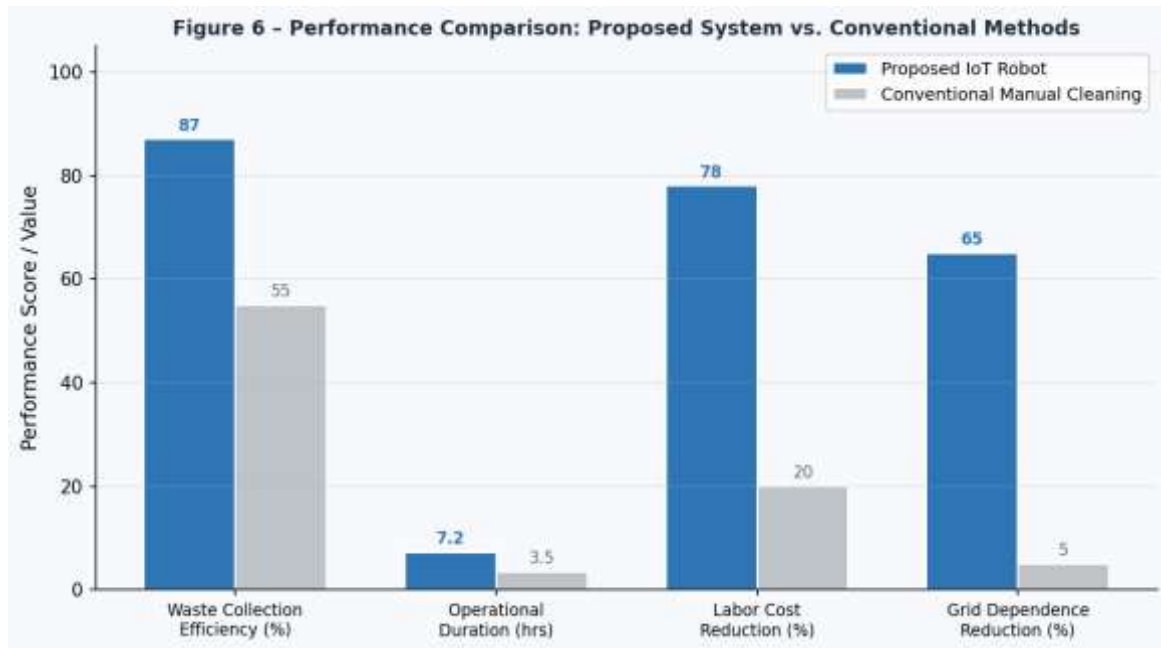


Figure 6 – Performance Comparison: Proposed IoT robot vs. conventional manual cleaning across four key performance metrics

Compared to conventional manual cleaning methods, the proposed system demonstrated substantially higher waste collection efficiency (87% vs. 55%), longer operational duration per deployment (7.2 hrs vs. 3.5 hrs), significantly reduced labor cost requirements, and substantially lower grid energy dependence through solar integration.

6.4 Solar Output and Battery Voltage

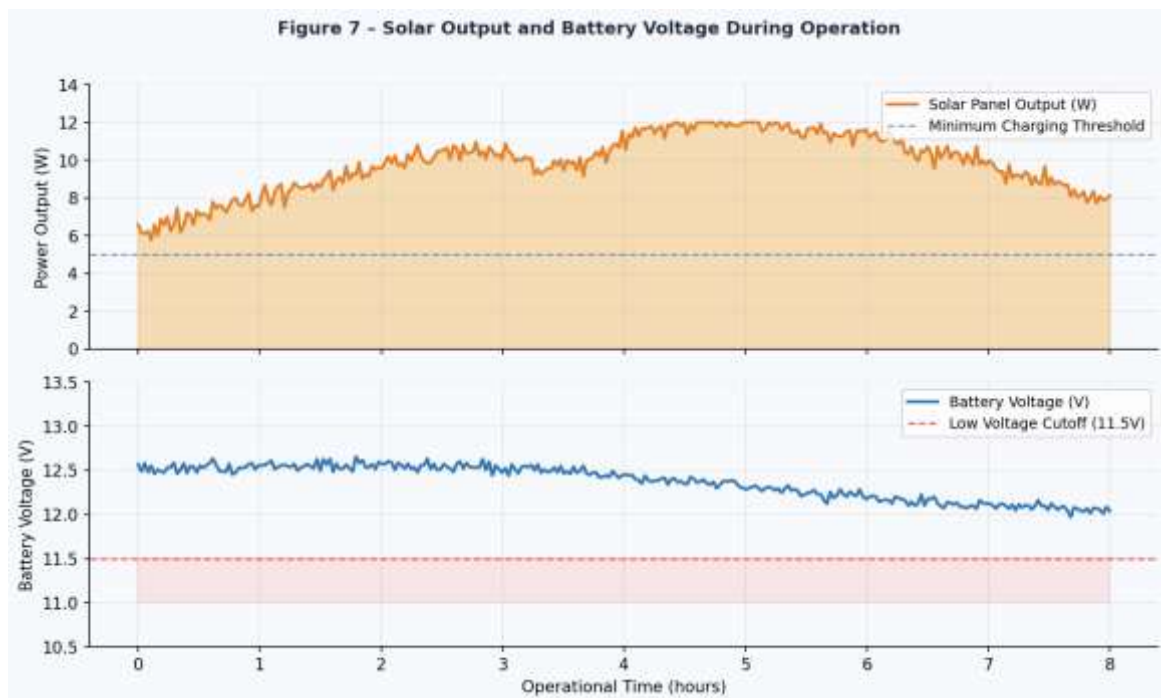


Figure 7 – Solar Output and Battery Voltage During Operation: Solar panel power profile (top) and corresponding battery voltage trace (bottom) over an 8-hour deployment

The solar panel produced peak output of approximately 12W under clear-sky conditions during midday hours, with characteristic dips during cloud passage events. Battery voltage remained stable throughout, with only gradual decline reflecting the net positive energy balance under good irradiance. Under overcast conditions, battery voltage declined more steadily, validating the identified need for higher-capacity storage in extended deployments under suboptimal irradiance.

6.5 Navigation and Connectivity

The NodeMCU established Wi-Fi connectivity in all test environments within standard home and institutional network range. Directional commands executed with latency below 200ms, providing responsive real-time control. Wi-Fi signal degradation was observed beyond approximately 30 meters from the access point, confirming that extended remote deployments will require additional network infrastructure or a transition to LoRaWAN communication.

6.6 Key Challenges Identified

- Net chamber finite volume required periodic manual emptying in heavily polluted zones, limiting extended autonomous operation.
- Robot maneuverability was reduced by wind-driven surface currents and floating vegetation mats exceeding gear motor torque rating.
- Wi-Fi range constrained deployment to proximity of existing network infrastructure.

7. Advantages of the Proposed System

7.1 Automation and Reduced Human Intervention

Remote IoT-based operation eliminates the need for human workers to be physically present near polluted water. A single operator can manage the robot from a safe location, reducing both labor costs and occupational health risks.

7.2 Energy Efficiency and Solar Integration

The combination of lightweight design, DC gear motor propulsion, and solar charging creates a system consuming significantly less energy than mechanized cleaning vessels while supporting deployment in locations without accessible charging infrastructure.

7.3 Environmental Sustainability

By removing floating plastic waste and organic debris, the robot directly contributes to ecosystem preservation. The absence of fuel combustion eliminates emissions associated with conventional cleaning vessels.

7.4 Cost-Effectiveness and Scalability

Use of widely available, low-cost embedded electronics — notably the NodeMCU platform and L298N motor driver — keeps manufacturing costs accessible for municipal programs and academic institutions. The modular architecture enables straightforward upgrades and multi-unit fleet deployment.

8. Applications

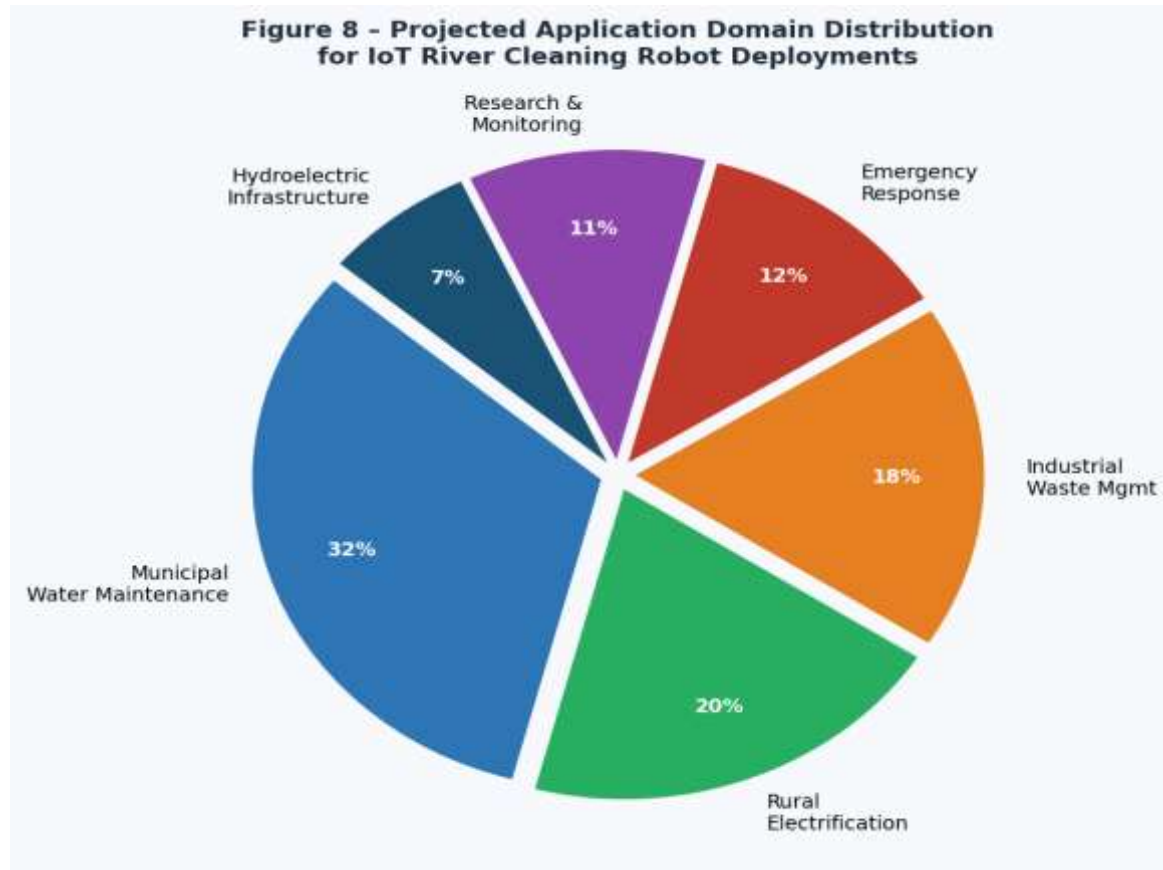


Figure 8 – Projected Application Domain Distribution for IoT River Cleaning Robot Deployments

8.1 Municipal Water Body Maintenance

Urban municipalities managing rivers, canals, retention ponds, and lakes can deploy the robot as part of routine environmental maintenance programs, enabling a single operator to manage multiple water bodies with minimal staffing overhead.

8.2 Industrial Waste Management and Infrastructure

Industrial facilities near water bodies can use the system to intercept waste before downstream accumulation. Hydroelectric plants benefit from proactive debris interception upstream of turbine intakes, reducing maintenance costs and operational disruptions.

8.3 Environmental Research and Disaster Response

Equipped with water quality sensors in future iterations, the robot can collect spatially distributed environmental measurements during cleaning. For disaster response, its rapid deployment capability supports post-flood surface clearing and emergency environmental remediation.

9. Conclusion and Future Scope

9.1 Conclusion

This paper presents the design, development, and evaluation of an IoT-enabled solar-powered river surface cleaning robot addressing the limitations of conventional manual and mechanized river cleaning. The system integrates a NodeMCU ESP8266 for Wi-Fi-based remote operation, an L298N motor driver for bidirectional propulsion, a passive net chamber for waste collection, and a solar-charged 12V battery for extended operational duration.

Testing confirmed effective floating debris collection in calm water conditions, reliable remote control response through the IoT interface, and sustained operation through solar energy harvesting. Compared to conventional approaches, the system demonstrated substantially higher collection efficiency, longer operational duration, reduced labor cost requirements, and lower grid energy dependence.

9.2 Future Scope

- **Autonomous Navigation via GPS and AI:** Integration of GPS modules and computer vision-based object detection would enable fully autonomous operation, allowing the robot to execute pre-programmed cleaning routes or dynamically optimize its path toward high-pollution zones.
- **Extended Wireless Communication:** Replacing Wi-Fi with LoRaWAN or GSM modules would extend operational control range to kilometers, enabling deployment in remote river systems far from existing network infrastructure.
- **Expanded Waste Collection Architecture:** A larger-volume net chamber with onboard compression or automated offloading would extend continuous operating time between disposal trips.
- **Multi-Sensor Environmental Monitoring:** Adding pH, dissolved oxygen, turbidity, and conductivity sensors would allow simultaneous waste collection and comprehensive water quality data acquisition.
- **Fleet Coordination and Smart City Integration:** A multi-robot coordination framework would enable collaborative cleaning operations with aggregate data feeding smart city environmental management dashboards.
- **Enhanced Solar Architecture:** Increasing solar panel capacity and integrating intelligent power management firmware would improve energy self-sufficiency in monsoon and overcast climates.

References

- [1] Khan, A., Sharma, R., & Patel, S. (2020). Autonomous water surface robot for waste collection in rivers. *International Journal of Robotics and Automation*, 15(3), 234–245.
- [2] Sharma, M., Singh, P., & Gupta, V. (2019). Solar-powered water cleaning robot with manual remote control. *Journal of Environmental Engineering and Technology*, 27(4), 567–574.
- [3] Mandal, S., Kumar, D., & Sen, A. (2021). Development of solar-powered autonomous cleaning robot for water bodies. *Renewable Energy and Sustainability Journal*, 12(2), 98–107.
- [4] Singh, P., Roy, R., & Mehta, A. (2021). IoT-based control of an autonomous cleaning robot using NodeMCU. *International Journal of Smart Systems and Robotics*, 8(1), 89–97.
- [5] Gupta, H., Jain, N., & Pandey, R. (2020). Design and implementation of DC gear motor-based water cleaning robot. *Mechanical Design and Innovation Journal*, 14(2), 312–320.
- [6] Liu, X., Wang, Y., & Zhang, Q. (2019). Energy-efficient power management in solar-powered autonomous robots. *IEEE Transactions on Sustainable Energy*, 10(4), 2056–2064.
- [7] Gupta, R., Soni, K., & Mishra, D. (2022). IoT and renewable energy-based river cleaning robots: A review. *International Journal of Environmental Engineering*, 15(2), 148–157.
- [8] Raj, A., & Kumar, S. (2021). Wi-Fi-controlled river cleaning robot: Design, development, and performance analysis. *Journal of Advanced Mechanical Engineering*, 28(3), 345–354.
- [9] Prakash, A., & Rao, D. (2020). Design of an energy-efficient propulsion system for autonomous water surface robots. *International Journal of Robotics and Mechanical Systems*, 17(2), 156–164.
- [10] Yadav, M., & Agarwal, S. (2020). Solar energy in autonomous robotic systems for environmental sustainability. *Journal of Solar Energy and Applications*, 19(3), 221–230.