

## Aquaboat: A Smart Web Integrated Robot

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**Abstract** – The Escalating global crisis of riverine plastic pollution represents a profound ecological emergency, necessitating a paradigm shift from conventional, labor-intensive cleaning methodologies toward intelligent, automated remediation platforms. This paper details the systematic engineering and implementation of Aquaboat, a high agility, semi-autonomous robot designed to bridge the technological chasm between hazardous manual collection and cost-prohibitive industrial dredging. The robot's hardware architecture features a robust quad-propulsion configuration utilizing high-torque DC motors to maintain operational stability and precise maneuverability within unpredictable urban river dynamics. Waste retrieval is facilitated by a front-mounted, motorized conveyor mechanism that systematically harvests surface-level anthropogenic debris. At the core of the system's intelligence is an ESP32 microcontroller, enabling real-time sensor data fusion and seamless remote operation via a custom IoT web interface. Looking forward, the research establishes a roadmap for transitioning the platform into a fully autonomous, self-sustaining system by integrating Raspberry Pi-based Edge AI for real-time computer vision and object detection. To achieve continuous round-the-clock operation, the next iteration will incorporate high-efficiency solar harvesting modules for energy independence and an automated waste collection bin mechanism to allow for uninterrupted cleaning cycles. By combining precision mechanical engineering with scalable embedded systems and future-ready autonomous capabilities, the robot platform offers a proactive and economically viable framework for the continuous restoration of aquatic ecosystems.

**Key Words:** ESP32, Web based Monitoring, Quad Propulsion, Conveyor Mechanism, Aquatic Ecosystem Sustainability, IoT, Sensor Data Fusion, Smart Waterway Management.

### 1. INTRODUCTION

Rivers serve as indispensable freshwater resources that sustain ecological stability, agricultural productivity, and human survival. However, accelerated urbanization and

inefficient solid waste management have transformed these vital waterways into primary transit points for anthropogenic debris. Every year, millions of tons of plastic waste transition from urban drainage systems into the oceans, creating a global ecological emergency. Once introduced into the aquatic environment, these pollutants degrade water quality and decompose into microplastics that lethally compromise local wildlife and downstream ecosystems. Despite the escalating severity of water contamination, current remediation methodologies remain fundamentally outdated. Conventional cleaning predominantly relies on manual labor, which is inherently slow, economically inefficient, and subjects workers to hazardous, polluted environments. Conversely, large-scale industrial dredgers are often prohibitively expensive for smaller municipalities and lack the agility required to navigate on narrow or shallow river segments. This creates a critical "technological gap" for an affordable, agile, and intelligent system capable of continuous surface-level remediation without human risk. To address this challenge, this project presents the implementation of Aquaboat, a semi-autonomous robot designed for targeted aquatic waste management. Bridging the gap between manual labor and heavy machinery, it utilizes a high-torque quad-propulsion system to maintain precise maneuverability under variable river currents. The system features a customized floating chassis design with front-mounted motorized conveyor mechanism engineered to systematically retrieve floating debris and transfer it into a secure onboard containment bin. The operational intelligence of the system is powered by an integrated control architecture specifically utilizing the ESP32 microcontroller for real-time navigation and sensor data fusion. By leveraging dual core processing, the system manages simultaneous tasks including debris level monitoring and remote communication via a custom IoT interface. This allows operators to monitor performance and control the robot from a safe distance through a web-based dashboard. By combining robust mechanical design with modern IoT capabilities, this paper details the design and experimental validation of Aquaboat as a scalable, low-cost solution for smart waterway management.

## 2. LITERATURE REVIEW

The research paper "Various Methods of River Water Cleaning" presents a comprehensive review of modern techniques used to reduce river water pollution and restore aquatic ecosystems. Rivers are a major source of drinking water, yet they are increasingly polluted due to industrial discharge, urban waste, agricultural runoff, and improper solid waste disposal. This pollution threatens public health, biodiversity, and environmental sustainability, making effective river cleaning methods essential. The paper discusses remote-controlled unmanned river cleaning bots as an efficient mechanical solution for removing floating waste such as plastics, garbage, and debris. These automated systems reduce human labor, risk, and operational costs while improving cleaning efficiency, especially in large river-cleaning programs. Biological treatment methods such as the Moving Bed Biofilm Reactor (MBBR) and Integrated Fixed Activated Sludge (IFAS) systems are analyzed in detail. These technologies rely on microbial biofilms attached to carrier media to remove organic pollutants, nitrogen, and phosphorus. MBBR is highlighted for its compact design, high pollutant removal efficiency, and low maintenance requirements, while IFAS improves sludge settling and enhances nutrient removal.

The paper also emphasizes aquatic phytoremediation, which uses aquatic plants to absorb and degrade contaminants from water and sediments. This eco-friendly method not only improves water quality but also provides additional benefits such as habitat creation, biodiversity support, and aesthetic enhancement. Additionally, aeration techniques are discussed for increasing dissolved oxygen levels to support microbial activity and reduce BOD, COD, odor, and color in polluted rivers. Finally, the study reviews bioremediation, which uses microorganisms to detoxify pollutants in situ or ex situ. The paper concludes that an integrated approach, combining mechanical, biological, and ecological methods, is the most effective and sustainable solution for river water cleaning. (1)

The research paper titled "River Cleaner Boat" presents the design and development of a low-cost, motorized river cleaning system aimed at reducing water pollution caused by floating solid waste. Rivers and ponds are essential natural resources, but rapid urbanization, improper waste disposal, and lack of effective waste management systems have resulted in the accumulation of plastic, bottles, and other garbage in water bodies. This pollution adversely affects water quality, aquatic life, public health, and the surrounding environment. The proposed river cleaner boat is designed to collect and remove floating waste from rivers, ponds, and lakes efficiently. The system is developed using simple and easily available components such as an Arduino Uno microcontroller, L298N motor driver, DC gear motors, HC-05 Bluetooth module, and a rechargeable lithium-ion battery.

The boat operates with the help of motors for movement and waste collection, while Bluetooth technology enables wireless control using a smartphone, making the system user-friendly and easy to operate.

The paper highlights the practical motivation behind the project, which was inspired by observing polluted local water bodies such as temple ponds and nearby rivers. The design focuses on reducing manual labor, minimizing health risks to workers, and providing a faster and safer alternative to traditional cleaning methods. The system is environmentally friendly, cost-effective, and safe for aquatic organisms. The study concludes that the river cleaner boat is an effective solution for routine cleaning of water bodies, especially in tourism areas, agricultural regions, and near industrial zones. With future enhancements such as solar power, automation, and sensor integration, the system has strong potential for large-scale implementation and sustainable river management. (2)

The document "A Holistic Approach for Cleanliness of River Ganga" presents an overview of the Government of India's flagship initiative, the Namami Gange Programme, aimed at pollution abatement, conservation, and rejuvenation of the River Ganga. Launched in 2014 by the Ministry of Jal Shakti, the programme adopts an integrated river basin management approach to restore the ecological and cultural significance of the Ganga, which supports nearly 47% of India's population and spans 11 states. The programme focuses on ensuring Nirmal Dhara (unpolluted flow) and Aviral Dhara (continuous flow) while maintaining the river's ecological integrity. A comprehensive Ganga River Basin Management Plan (GRBMP), prepared by a consortium of IITs, guides multi sectoral and multi-agency interventions. Key areas of intervention include pollution abatement through sewage infrastructure development, ecological restoration, public participation (Jan Ganga), and research and policy support (Gyan Ganga).

Significant progress has been achieved, with over 492 projects launched and more than 300 completed by January 2025. These include large-scale sewage treatment plants, interception and diversion of drains, industrial effluent control, biodiversity conservation, afforestation, and wetland development. The programme has substantially increased sewage treatment capacity and reduced the discharge of untreated wastewater into the river. Recent initiatives emphasize sustainable wastewater reuse, long-term operation of treatment facilities, and enhancement of aquatic biodiversity, including fish conservation. The document concludes that the Namami Gange Programme represents a comprehensive and sustainable model for river rejuvenation, combining infrastructure development, ecological restoration, policy reforms, and community engagement to ensure a clean and healthy River Ganga for future generations. (3)

The research paper titled “Remote Controlled River Surface Cleaning Robot” presents the design, development, and testing of an automated system aimed at addressing the growing problem of floating waste pollution in rivers and other water bodies. Rapid urbanization, industrial activities, and improper waste disposal have resulted in the accumulation of plastic debris, bottles, and organic waste on water surfaces, which severely impacts aquatic ecosystems, water quality, and public health. Traditional manual cleaning methods are labor-intensive, time-consuming, and hazardous, highlighting the need for a safer and more efficient alternative. The proposed system is a remote-controlled river surface cleaning robot that utilizes an ESP32 Wi-Fi microcontroller as the central control unit. The robot is equipped with geared DC motors for navigation and a conveyor belt mechanism for continuous collection of floating debris into an onboard storage bin. Wireless communication through Wi-Fi allows real-time control and monitoring of the robot using a mobile application, ensuring safe operation without direct human contact with polluted water.

The entire system is powered by a 12V lithium-ion battery, supported by a voltage regulation circuit to ensure stable operation of electronic components. The robot’s compact and lightweight design enables deployment in rivers, lakes, canals, and narrow water bodies where conventional cleaning equipment is ineffective. Experimental results demonstrate stable navigation, reliable debris collection, and effective remote operation under various conditions. The study concludes that the proposed robot offers a cost-effective, scalable, and environmentally friendly solution for surface water cleaning. With further enhancements such as automation and renewable energy integration, the system has strong potential for large-scale implementation in sustainable water pollution management. (4)

The research paper titled “Automated River Cleaning Robot for Plastic Waste Segregation Using AI” presents an intelligent and autonomous solution to address the growing problem of plastic pollution in rivers and water bodies. Plastic waste poses severe threats to aquatic ecosystems, biodiversity, and human health. To overcome these limitations, the authors propose an AI-based floating river cleaning robot capable of detecting, collecting, and segregating plastic waste with minimal human intervention. The proposed system utilizes computer vision and machine learning techniques for plastic-only detection, ensuring selective and efficient waste collection. A Raspberry Pi serves as the core processing unit, running TensorFlow Lite based object detection models such as YOLO and MobileNet. Real-time video input is captured using a Pi Camera, and plastic objects are identified with a confidence threshold of more than 80%. Once detected, a servo-controlled loading mechanism transfers the plastic waste into an onboard storage container.

To enhance traceability and monitoring, the robot logs GPS location data and time stamps using a NEO-6M GPS module and stores image evidence of collected waste. The system is designed to be energy-efficient, with the potential integration of solar power to extend operational duration. Additional sensors support obstacle detection and safe navigation on water surfaces. The study highlights that AI-driven river cleaning robots significantly outperform traditional cleaning methods in terms of accuracy, efficiency, scalability, and environmental sustainability. The paper concludes that the proposed system offers a cost-effective and reliable solution for large-scale plastic waste management in rivers, with future scope for multi-robot coordination and real-world deployment. (5)

The research paper titled “River Cleaning Robot Using Solar Power” presents the design and development of an eco-friendly robotic system aimed at removing floating waste from river surfaces. Increasing river pollution caused by plastic waste, leaves, and industrial debris has become a serious environmental issue, while traditional manual cleaning methods are inefficient, costly, and hazardous to workers. The proposed system addresses these challenges by combining robotics with renewable energy to achieve sustainable water surface cleaning. The river cleaning robot is powered by solar energy, using an 11.1 V lithium-polymer battery charged through a solar panel integrated with a Battery Management System (BMS). This ensures safe charging, efficient power usage, and extended operational time. The system is controlled by an Arduino Uno, which manages propulsion motors and a conveyor belt mechanism used to collect floating debris into a storage bin. L298N motor drivers and BO DC motors enable smooth movement and effective waste collection.

For remote operation, the robot employs an HC-05 Bluetooth module, allowing users to control movement and cleaning actions via a mobile device. Additionally, an ESP32-CAM module provides live video streaming, enabling real-time monitoring and accurate navigation during operation. This feature improves safety and efficiency by reducing the need for direct human involvement in polluted water bodies. Experimental testing in a controlled water environment demonstrated reliable performance, with continuous operation exceeding two hours and effective collection of various floating wastes. The study concludes that the proposed system is a low-cost, energy-efficient, and environmentally sustainable solution for river cleaning. Future enhancements such as autonomous navigation and AI-based waste classification could further improve scalability and effectiveness for large-scale river and lake cleaning applications. (6)

The research paper titled “SMURF: A Fully Autonomous Water Surface Cleaning Robot with a Novel Coverage Path Planning Method” presents the design, development, and

validation of an autonomous robotic system for efficient removal of floating waste from water surfaces. Manual river and water body cleaning is hazardous, labour intensive, and inefficient, especially over large areas. To overcome these challenges, the authors propose SMURF, a fully autonomous water surface cleaning robot capable of operating in diverse real-world environments such as rivers, lakes, coastal areas, and marinas. SMURF is designed with a dual-pontoon hull for stability, a front-mounted trash collection mechanism, and an onboard container for waste storage. The robot integrates advanced hardware including an NVIDIA Xavier NX processor, RTK-GNSS, IMU, RGB camera, and millimeter-wave radar to enable accurate localization, perception, and navigation. The system operates without human intervention once the cleaning boundary is defined.

A key contribution of the paper is a novel Water Surface Coverage Path Planning (WSCPP) algorithm, specifically developed for irregular water boundaries and obstacle-rich environments. Unlike traditional coverage methods, the proposed approach minimizes both path length and turning time, thereby improving overall cleaning efficiency. Additionally, an improved Nonlinear Model Predictive Controller (NMPC) with feed-forward compensation is introduced to handle dynamic changes in robot mass and environmental disturbances during operation. Extensive real-world experiments demonstrate that SMURF achieves complete surface coverage with high stability and accuracy. Performance evaluations show that SMURF significantly reduces cleaning time compared to manual methods while maintaining robust operation under varying conditions. The study concludes that SMURF is an effective, scalable, and practical solution for autonomous water surface cleaning and environmental protection. (7)

The research paper titled "Artificial Intelligence Enabled Robotic Trash Boat to Drive and Harvest Floating Trash from Urban Drain" presents the development of a semi-autonomous robotic system engineered for the removal of floating solid waste from urban drainage channels and narrow water bodies. Urban drains frequently suffer from blockages caused by plastic debris and waste accumulation, leading to water stagnation, health hazards, and infrastructure damage. Conventional manual cleaning practices expose workers to toxic gases, biological risks, and physical injuries, necessitating an automated alternative. The proposed robotic trash boat is built around an Arduino UNO microcontroller, which coordinates sensing, actuation, and navigation tasks. An ultrasonic sensor is employed for real-time obstacle and debris detection, enabling adaptive path correction and selective waste collection. Locomotion and collection mechanisms are powered using BO DC geared motors, interfaced through L298D and L293D motor driver modules, providing bidirectional motor control and speed regulation. The waste collection unit consists of a front-mounted hylem sheet assembly, which mechanically guides floating debris into an onboard storage bin.

Power is supplied using a rechargeable 18650 lithium-ion battery, with provisions for solar backup to enhance operational endurance. The system is designed to autonomously navigate confined drainage paths, detect obstructions such as riverbanks, and reroute without external control. Experimental evaluation demonstrated reliable waste detection up to 40 cm and the ability to carry loads of approximately 7 kg, validating mechanical stability and control accuracy. The study concludes that the proposed robotic platform offers a low-cost, modular, and energy-efficient solution for urban drainage maintenance. The architecture allows future upgrades such as waste classification, improved perception algorithms, and enhanced autonomy, making it suitable for scalable deployment in smart city sanitation systems.(8)

The paper "AI Based River Cleaning Robot" (2025) addresses the critical environmental issue of water contamination by developing an autonomous solution to replace labor-intensive and hazardous manual cleaning methods. The researchers developed a floating robotic platform centered around a Raspberry Pi 5 processing unit, which utilizes artificial intelligence and computer vision to identify debris like plastic bottles and organic waste in real-time. For visual recognition, the system employs a camera module and deep-learning models such as YOLO or Mobile Net to generate bounding boxes around detected waste. Once the AI identifies debris, control commands are sent to an L298N motor driver, which regulates four gear motors for propulsion and a conveyor belt mechanism to lift and store the waste.

During testing, the robot demonstrated high detection accuracy under normal daylight, successfully identifying objects within a range of 1 to 1.5 meters. The integration of an ultrasonic sensor further allows the system to navigate safely by avoiding obstacles. While the study highlights the system's efficiency and low operational cost, the authors note that performance can be challenged by environmental factors like heavy water reflections, ripples, or partially submerged debris. Ultimately, the paper validates that combining low-cost embedded hardware with vision-based AI provides a scalable and environmentally friendly approach to maintaining the health of rivers and lakes. (9)

The research paper presents a comprehensive technical analysis of autonomous robotic systems developed for environmental remediation and hazardous waste management, addressing the growing limitations of conventional manual and mechanized clean up techniques. The study emphasizes the integration of advanced sensing architectures, intelligent navigation frameworks, and artificial intelligence-driven control strategies that enable robots to operate reliably in contaminated and high-risk environments. The paper systematically evaluates robotic platforms across terrestrial, aquatic, and aerial domains, including ground-based remediation robots, autonomous

surface vehicles (ASVs), and autonomous underwater vehicles (AUVs). These systems employ multispectral imaging, chemical and gas sensors, SLAM-based localization, and adaptive path-planning algorithms to detect, classify, and remove pollutants from soil, water bodies, and urban environments. Machine learning models enhance perception accuracy, anomaly detection, and decision-making under dynamic environmental conditions.

A significant contribution of the study lies in its assessment of technological maturity, reporting measurable improvements in sensor accuracy, navigation reliability in GPS-denied zones, and energy management efficiency. The paper highlights real-world deployments, such as robotic soil remediation in radioactive zones, automated oil spill recovery, and intelligent waste segregation in recycling facilities, demonstrating superior operational safety and efficiency compared to human-dependent methods. Despite these advancements, the authors identify persistent challenges, including sensor degradation in harsh environments, limited battery endurance, system maintenance complexity, and regulatory fragmentation. The study concludes by outlining future research directions focused on hybrid robotic systems, sensor fusion, swarm robotics, and sustainable energy solutions. Overall, the paper establishes autonomous robotics as a scalable and technically viable solution for next-generation environmental protection and hazardous waste remediation. (10)

In the research paper titled "Aqua Dredger River Cleaning Machine" (2020), authors Kaushal Patwardhan, Shivraj Hagawane, and Ashish Kalokhe address the escalating crisis of river pollution and the high costs associated with government initiatives like "Namami Ganga". The study details the design and fabrication of an economical, remote-operated machine specifically engineered to remove surface debris, sewage, and toxic materials from water bodies. The mechanical system utilizes a conveyor belt and chain drive arrangement powered by a motor to automate the collection process, thereby reducing the time and manual labor traditionally required for river maintenance. Constructed with a focus on cost-effectiveness and the use of available local resources, the "Aqua Dredger" is presented as a sustainable tool for urban and rural pond cleaning. The authors conclude that by automating these cleaning operations, the machine provides a safer, faster, and more affordable solution for society to improve water hygiene and protect aquatic ecosystems. (11)

In the research paper titled "River Cleaning Machine" (2021), authors Mr. G. G. Rathod, Suraj Varpe, Sanket Pawase, and Vikas Sahane propose a remote-operated mechanical system designed to address the inefficiencies and risks associated with manual water cleaning. The system utilizes a conventional conveyor belt mechanism to scoop floating solid waste from the water surface, but introduces a

significant modification: an Air Tube Piping Guider mechanism. This innovation is designed to improve the collection efficiency by guiding floating debris toward the conveyor more effectively than standard models. The machine is controlled via a remote-control system, allowing operators to clean rivers and ponds from the shore, thereby eliminating the need for a large workforce and reducing the physical risks to workers. By focusing on a design that is effective, efficient, and eco-friendly, the authors conclude that this modified mechanical approach provides a superior alternative to traditional boat-based or manual collection methods, offering a practical solution for the ongoing maintenance of national water bodies. (12)

The paper "Aqua-Cleaner using Raspberry Pi, ESP32 and LoRa" (2025) presents an advanced semi-autonomous system designed to overcome the communication and autonomy limitations of traditional Arduino-based water cleaning robots. The architecture utilizes a tiered processing approach where a Raspberry Pi handles high-level computer vision and decision-making, while an ESP32 manages low-level motor and conveyor belt operations. A significant innovation in this research is the integration of LoRa (Long Range) technology, which enables real-time monitoring of the robot's parameters over distances of several kilometers, making it suitable for large-scale smart city applications. In practical evaluations, the system demonstrated a high waste collection efficiency of 88% in calm water, though this performance decreased to 65% in stronger currents due to mechanical challenges such as conveyor misalignment. The robot uses computer vision to detect and identify floating waste, such as plastic bottles and leaves, though it faced difficulties identifying smaller or partially submerged items. The study concludes that this multi-controller and long-range communication approach offers a more sustainable and scalable solution for environmental maintenance, with a total power consumption of approximately 15W and a battery life of 4 hours per charge. (13)

The previous research paper titled RIVENTO: "Aquaboat" presents the design and development of an autonomous river surface cleaning system aimed at addressing the growing issue of water pollution caused by floating waste. The system utilizes a Raspberry Pi-based embedded control architecture integrated with multiple sensors such as ultrasonic bin-level sensors, infrared obstacle detection sensors, water-level sensors, and temperature sensors to enable intelligent operation and safety. It employs a motor-driven conveyor mechanism to efficiently collect floating debris and transfer it into an onboard storage unit, while quad DC motors provide stable propulsion and maneuverability in varying water conditions. The system is capable of real-time data processing to optimize cleaning performance and ensure safe operation. A key feature of the system is its ability to reduce human intervention through autonomous navigation and continuous monitoring. The proposed solution is energy-efficient, modular, and scalable,

making it suitable for practical deployment in river cleaning and environmental management applications. (14)

### 3. SYSTEM METHODOLOGY: MODIFIED APPROACH

#### I. Architecture of the system

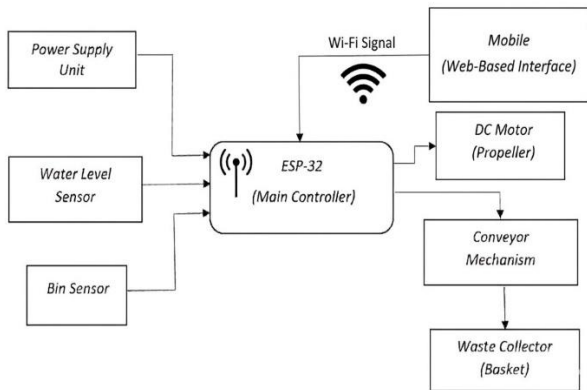


Fig -1: Architecture of the implemented system

The Aquaboat is an innovative, semi-autonomous robotic platform designed to address the critical challenge of floating solid waste in urban and inland water bodies. At its core, the system utilizes a high-efficiency conveyor belt mechanism driven by a dedicated DC gear motor, which systematically scoops debris from the water surface and deposits it into an integrated storage bin. This mechanical recovery process is supported by a unique quad-propulsion system, where four independent propellers provide the high-torque maneuverability required to navigate unpredictable river currents and stagnant pond environments with precision. By replacing traditional manual cleaning methods with this mechanized approach, the project significantly reduces the safety risks associated with human exposure to polluted or hazardous water.

The "intelligence" of the robot is powered by an ESP32 microcontroller, leveraging its dual-core architecture to manage simultaneous tasks of real-time navigation and sensor data processing. The boat features a custom IoT enabled web-based interface, allowing operators to monitor and control the robot remotely from any smartphone or laptop via a dedicated Wi-Fi hotspot. Upon connecting to the onboard Wi-Fi hotspot, the operator must first provide a valid username and password through a secure login portal. Only after successful authentication is the user granted access to the primary control dashboard, where they can monitor the robot and manage its movements remotely via any smartphone or laptop. To ensure operational reliability, the system integrates intelligent sensors, including an ultrasonic bin-level monitor to prevent waste overflow and a water level sensor to track the robot's buoyancy and structural integrity. Powered by high capacity Lithium-Ion

batteries, the Aquaboat prototype offers zero carbon emission operation, making it a scalable and cost-effective solution for sustainable environmental remediation.



Fig -2: Administrator login page of website



Fig -3: Robot control dashboard



Fig - 4: Prototype model of the system

## II. Operational Algorithm & Logic Sequence

The operational framework of the developed prototype is governed by a structured control logic integrated into the ESP32 microcontroller. The system follows a sequential execution path, transitioning from hardware initialization to real-time manual intervention via a dedicated Graphical User Interface (GUI).

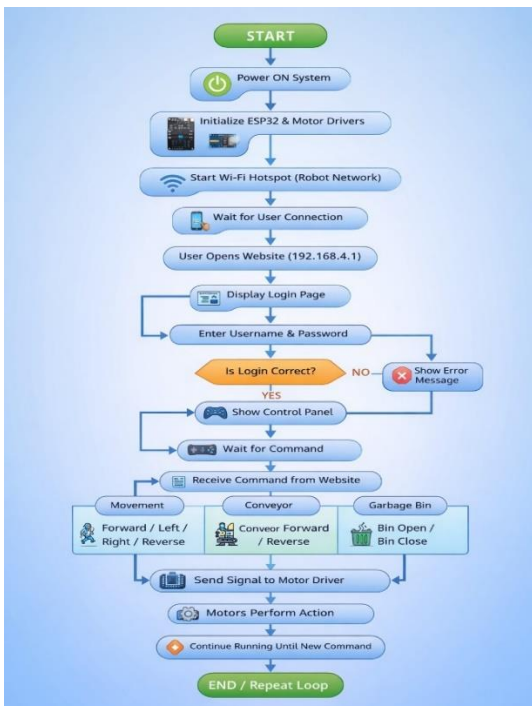


Fig - 5: Basic workflow of system

### 1. Initialization and Network Establishment

Upon system activation, the firmware executes a self-test to initialize the ESP32 and the integrated motor drivers. To ensure independence from external network infrastructure,

the ESP32 is configured in Access Point (AP) Mode. This creates a localized Wi-Fi hotspot, allowing the operator to establish a direct peer-to-peer connection. The control interface is hosted on a local web server, accessible via the static IP address 192.168.4.1

### 2. Authentication and Security Layer

To prevent unauthorized access and ensure operational safety, a security handshake is implemented. The system serves a login page requiring credential verification. The logic utilizes a conditional gateway: if the inputs match the predefined parameters, the web-based control panel is initialized; otherwise, an exception is handled via an error message, and access remains restricted.

### 3. Command Execution and Actuation

The core functional logic is divided into three primary subsystems, managed through a continuous listening loop:

- Navigation Subsystem: Processes directional inputs (Forward, Reverse, Left, Right) to coordinate the quad-propulsion or steering motors.
- Collection Subsystem (Conveyor): Manages the front-mounted conveyor mechanism. The logic supports bi-directional rotation to facilitate both the intake of floating debris and to discharge the accumulated garbage from the bin through conveyor at a designated collection point.
- Storage Subsystem (Garbage Bin): Controls the actuation of the bin collect/discharge modes, allowing for the containment of collected waste or the discharge of materials at a designated collection point.

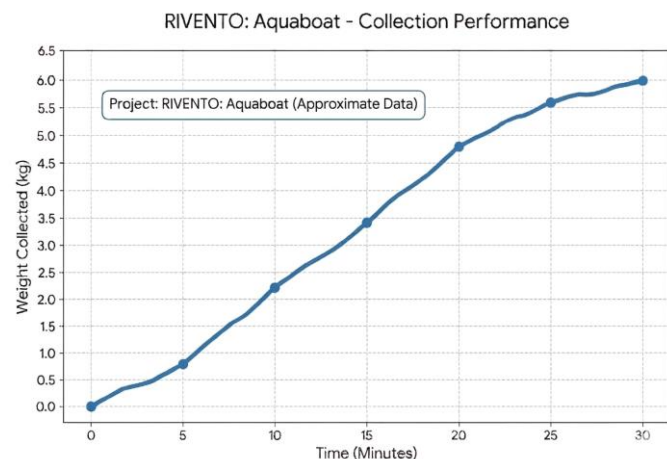
### 4. Signal Processing and Feedback Loop

Once a command is received via the web interface, the ESP32 translates the digital instruction into Pulse Width Modulation (PWM) signals. These signals are transmitted to the motor drivers, which regulate the current flow to the DC motors. The system is designed to maintain the current state of operation such as continuous conveyor movement until a subsequent "Stop" or "New Command" signal is registered, ensuring efficient power management and smooth mechanical operation.

## 4. RESULTS

The proposed Aquaboat system was successfully implemented and experimentally evaluated under controlled aquatic conditions to assess its operational performance in terms of navigation stability, waste collection efficiency, and communication reliability. The system demonstrated

consistent and stable locomotion using a propeller-driven propulsion mechanism, enabling precise directional control with minimal drift under low-flow water conditions. The ESP32-based control architecture exhibited reliable real-time communication with the web-based interface over Wi-Fi, with an average command-response latency of approximately 1 to 2 seconds. This ensured effective remote operation and synchronization between user inputs and system actuation. The motor control subsystem, interfaced through the L298N driver module, provided adequate torque and speed regulation for both propulsion and conveyor operations. The conveyor-based waste collection mechanism achieved continuous and effective removal of floating debris, including plastic materials and organic waste. Experimental analysis indicates that the system attained a waste collection capacity of approximately 6 kg within 30 minutes, corresponding to an average collection rate of 0.2 kg per minute under test conditions.



**Chart -1:** Performance analysis of the system

The mechanical design ensured smooth transfer of debris into the onboard storage bin without significant blockage or loss. Sensor integration further enhanced system reliability and safety. The bin-level monitoring system provided real-time feedback on storage capacity, enabling timely intervention, while the water-level sensor effectively detected abnormal conditions such as leakage or excessive submersion. The overall system operated in a closed-loop manner, continuously processing sensor inputs and executing control commands. The experimental results validate that the proposed system achieves improved efficiency, reduced human intervention, and enhanced operational safety compared to conventional manual cleaning methods. The integration of IoT-based communication, embedded control, and mechanical waste collection establishes the system as a scalable and cost-effective solution for water surface cleaning applications.

## 5. CONCLUSION

This research presents the successful design and implementation of the Aquaboat, an IoT-enabled remote-controlled river cleaning robot developed to address the growing challenge of water surface pollution. The proposed system integrates embedded control, wireless communication, and electromechanical actuation into a unified architecture, enabling efficient and real-time waste collection with minimal human intervention. The use of the ESP32 microcontroller ensures low-latency communication and seamless web-based control, while the conveyor-driven collection mechanism enhances debris retrieval efficiency under dynamic aquatic conditions. Experimental evaluation confirms that the system achieves reliable navigation, stable operation, and effective waste collection performance, demonstrating a measurable improvement over conventional manual cleaning approaches in terms of safety, efficiency, and cost-effectiveness. The incorporation of sensor-based monitoring further strengthens system robustness by enabling real-time feedback and preventive safety mechanisms.

From a broader perspective, the Aquaboat establishes a scalable and adaptable framework for intelligent water surface cleaning systems. Its modular design allows seamless integration of advanced technologies such as Edge AI, computer vision, and renewable energy systems, paving the way toward fully autonomous and self-sustaining environmental robotics. Thus, the proposed system not only addresses immediate pollution challenges but also contributes to the evolution of smart, sustainable, and technology-driven water management solutions.

## 6. FUTURE SCOPE

The future evolution of the Aquaboat will focus on transitioning to a fully autonomous, self-sustaining system through the integration of a Raspberry Pi and solar harvesting modules. By leveraging Raspberry Pi's computational power, the next iteration will implement Edge AI and Computer Vision for real-time object detection, enabling the system to autonomously distinguish between hazardous debris and aquatic life. To ensure operational independence, high-efficiency solar panels will be integrated to recharge the Lithium-Ion batteries during deployment, significantly extending the mission duration for long-term clean-up operations. Furthermore, the Raspberry Pi will facilitate GPS based navigation, intelligent path planning, and advanced environmental sensing for continuous monitoring of water quality parameters. In addition, the system can be further enhanced to support continuous round-the-clock operation by incorporating a removable or automated waste collection bin mechanism, allowing uninterrupted cleaning without frequent manual intervention. This technological roadmap will transform Aquaboat from a remotely operated

system into a fully autonomous, pro-active solar powered intelligent platform.

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