Floating Debris Scooper Robot

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***Abstract*— Rapid population growth, Urbanization and Industrialization has resulted in increased production of solid and plastic waste. With ever-growing population and insufficient infrastructure for garbage disposal and recycling, water bodies are becoming the disposal place for the garbage. Accumulation of floating garbage on water surface leads to clogged drains, water stagnation and act as breeding ground for the diseases. This not does only effect the water ecosystem but the whole surrounding environment. Traditional cleanup methods are often expensive, labor intensive, time consuming and insufficient compare to the rising scale of pollution. In response to these problems, a Floating Debris Scooper Robot can be seen as a reliable solution. To collect the plastic pollution, semi-manual plastic and garbage collecting vessels are being deployed however they are feasible for large amount of waste accumulation and rivers and lakes with large surface area. Though no technology is compared to the awareness among the people and a strong garbage disposal and recycling infrastructure.**

This paper studies the current status of Floating Debris Scooper Robotics, synthesizing evidence to determine their practicality, viability, and future trajectory. The study shows that these technologies are evolving from simple, remote-controlled devices to complex, data-driven systems capable of autonomous navigation, real-time waste sorting, and integration with larger metropolitan infrastructure. Despite ongoing obstacles such as power endurance, bycatch, and the constraints of surface-only collecting, the long-term economic rationale for automation remains compelling. The report emphasizes the importance of these systems as a scalable and effective solution for catching pollution at major entrance sites, as well as suggesting future research areas to remove existing barriers and fully realize their promise.

"Floating Waste Scooper Robot" deals the above problem by giving a reliable solution. This project focuses on designing a robot which is able to operate with high stability in water, catamaran hull design is used for stability. Conveyor belt is used to collect the trash which is drive by motors, the collected trash is stored in a bin mounted on robot. The power supply is given through the battery which can additionally be charged through solar panel. The robot is remotely controlled through the web app interface and connection is established through Wi-Fi. Additional sensors and parameters include GPS location, Weight measurement, IMU sensor, TDS sensor which ensures the ease of operation.

Keywords*— *Floating Plastic Pollution, Garbage Collector Robot, Trash Management, Renewable Energy Used, Water Contamination, Water Surface Cleaner, Unmanned Devices, Remote Controlled, Robot Automation, Marine Debris Impact, Aquatic pollution Prevention, Autonomous Surface Vessels

I. INTRODUCTION

Water is the one of the most valuable resource available on the Earth which is vital for survival of all kinds of life forms present here. Water covers 71% of the earth surface out of which only 2.5% is fresh water and only 1% is accessible to humans for consumption and is potable. This potable water is also being polluted due to human negligence during disposal of waste material. This negligence has led to the accumulation of waste for decades. This waste accumulation is not only present in drains and river but it travels to the vast oceans and accumulate there.

This paper introduces the Floating Debris Scooper Robot, an innovative solution developed to combat the significant environmental issue of water pollution caused by floating waste in rivers and water bodies. Traditional manual cleaning methods are often laborious, hazardous, and time-consuming. This robot addresses these limitations by integrating robotics and Internet of Things (IoT) technology to provide an efficient, automated, and sustainable cleaning and monitoring system that reduces human effort and promotes environmental conservation.

The robot is designed as an autonomous floating machine. It uses DC motors and propellers for stable navigation, and a conveyor belt mechanism to efficiently collect floating debris (plastics, bottles, etc.) and transfer it into an onboard storage container. Safety is managed by ultrasonic sensors for obstacle detection, preventing collisions. Beyond mechanical cleaning, the robot serves a dual purpose by monitoring water quality in real time using integrated pH, turbidity, and temperature sensors, allowing for immediate assessment of the water's condition.

IoT integration is crucial to the robot's functionality, utilizing microcontrollers like the ESP32 or GSM modules to connect to the internet. This connectivity allows the system to transmit live data on water quality, operational status, and waste levels to a cloud platform or mobile application. This enables remote monitoring and control, allowing users to supervise performance and receive automatic alerts for full waste containers or maintenance needs, thereby minimizing the need for constant human supervision.

For enhanced sustainability, the system is designed to be powered by solar energy. Solar panels recharge the onboard battery, allowing for extended, autonomous operation in outdoor environments without relying on conventional power sources. Furthermore, the potential integration of GPS technology could be used to track the robot's location and define precise navigation paths, ensuring comprehensive cleaning coverage. Ultimately, the robot offers a versatile and intelligent solution for environmental preservation by efficiently automating waste collection and providing valuable data for authorities to analyze pollution and take corrective action

II. CONSTRAINTS OF CONVENTIONAL CLEANUP METHODS

Traditional methods for cleaning marine environments are often manual or rely on manually operated devices. While the traditional method is used there are many hurdles in it such as labor safety, economic strain and operational challenges. The process requires large manpower and is susceptible to unpredictable delays due to weather or equipment failures, leading to overtime pay and prolonged project timelines which is economically challenging.[3] While manual cleanup may appear to have a lower per-hour rate, its hidden costs and risks make it unsustainable in the long term.[3]

In addition to these visible costs, manual cleanup poses significant and often overlooked safety risks towards human laborers. Labors are exposed to biological hazards (pathogens like bacteria and viruses), chemical agents, and physical dangers from slips and falls.[4] The presence of decaying organic waste can create a harmful working environment such as oxygen-deficiency and flammable or toxic gases like methane and Sulphur compounds, which are colorless and odorless and lethal to humans.

III. ROBOTIC WASTE GATHERER: CORE TECHNOLOGIES AND ANALYSIS

A. Classification of Aquatic Cleanup Robots

The properties, design and features of aquatic cleanup robots vary significantly based on their application and operational environment. The design of these systems can vary on the basis of vessel design, collection mechanism, operational scope and power constrains. The Primary collection mechanisms are:

- Conveyor- belt type: This is one of the most widely used type of structure, utilizing a conveyer belt with claws, teeth or separation to scoop floating debris from the water's surface into collection bin. [6,8,9,10]

- Robotic arm type: Some prototypes use robotic arm to pick-up and collect the garbage mainly in more controlled environment like pool and drain or in still water like ponds and puddles which is stored in the collection bin behind. [7,9,15]

- Suction Type: This type of structure is typically used for the cleaning of small area; using the concept similar to a vacuum cleaner. The plastic particles are sucked up by the robot then it is separated from water using high speed rotation and filter screen. [12]

- Vortex type: Devices like Seabin which are attached to a rigid support; they float on surface of water. A small pump is used to draw water from the surface creating a vortex that pull the floating debris into a catch bag. This method is typically used for capturing small particles and microplastics. [13,14]

- Barrier/ Net Type: These systems use floating barriers and nets to collect debris. A net is attached to the rigid anchor or to a moving robot to collect the waste which is floating or partially sunken in the water.[5]

The design of the robot is chosen and modified according to the specific working environment and application. Catamaran shaped hulls are most common type like in conveyor system, net using robots & Robotic arm type of design. Whereas a trash bin type of structure with rigid support connection is used by the Seabin.

B. Key Components and Parameters

- Power Consideration: Power is the biggest obstacle in the process. The main goal is to collect maximum amount of waste with minimal power used. Today most system rely on re-chargeable batteries (Lithium-ion) whereas conventional system rely on fossil fuels. To extend the operational hours, many systems use solar panels.

- Propulsion system: The propulsion system chosen based on the operational area, operational hours, maneuverability and speed of the robot. The propulsion system varies from simple paddles attached to the motors to aqua jets.

- Control and communication system: The control and communication system are important for monitoring and controlling the operations. Low-cost prototypes use app enabled with Bluetooth or Wi-Fi, remote control via radio transmitter can also be used. Autonomous system uses advance systems like 4G communication for real time monitoring.

- Waste collection system: Nowadays advance system is AI enabled which are autonomous; they detect, maneuver and collect debris with no or minimal human intervention but are costly. System which are comparatively of low cost rely on humans for their operational controlling
- Physical Structure: Construction of hull and body is application specific, commercial robots use catamaran design with aluminum hulls or custom design hulls. Prototypes often use cheap materials like PVC pipes, acrylic boards etc. The main goal is to make a durable structure with considerable buoyancy. The robot must be able to resist corrosion and harsh marine conditions.
- Sensor and Navigation: Conventional robots rely on Ultrasonic sensor, cameras and primarily human control for navigation. For autonomous systems they mainly rely on radar system (LiDAR), cameras for identification and collection of system along with inertial navigation for stability. GPS system is used for route planning and positioning.

- Integration of AI: Modern systems use the computer vision (CV) and AI to identify and classify the waste in real time. These robots are equipped with high resolution cameras that along with Machine Learning (ML) like You Look Only Once (YOLO) and Convolutional Neural Networks (CNNs) help identify the different types of trash. Also, there are algorithms for path optimization. It can also help identify pollution hotspots and predict waste trends.

Additional features of the robot include analysis of other parameters of the water namely temperature, pH, turbidity, TDS etc. to get an estimate about quality of water.

C. Methodology Comparison of Different Systems.

1) Remote/IOT Based System or Autonomous System

- While many robots operate on app command with the help of input from IoT based sensors [5,9,10,12] and remote control [8].
- The IWSCR [7] works autonomously with the help of AI {YOLOv3}; Sea bins operate on the continuously [13] or when waste is detected in its proximity [14].
- Additionally, 'Economic Floating waste Detection for Surface Cleaning Robots' [15] use laser for autonomous operation.

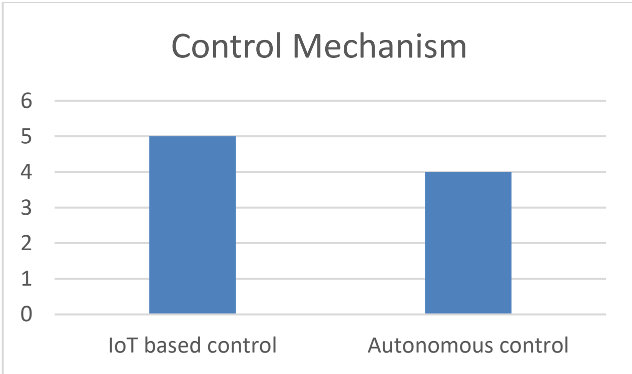

Fig. 1. Comparison of Control Mechanism Used

2) Waste Collection Mechanism

- The most common approach for the waste collection is the conveyor belt [8,9,10,15].
- The Seabin use a bin made up of nylon mesh to trap the waste [13,14].
- The IWSCR [7] uses a robotic arm to catch the floating waste. Two robots Also have side scooper arms. [9,15]
- The 'Miniature Water Surface Garbage Cleaning Robot' [12] uses vacuum like suction to trap small floating debris.
- The Fig. 2 shows the types of waste collection mechanism used.

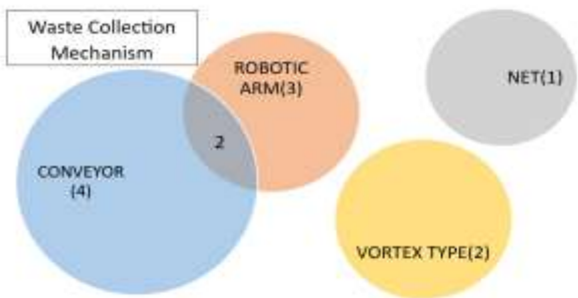

Fig. 2. Waste Collection Mechanism Used

3) Detection and navigation technology

- The widely used approach for detection and navigation in the prototype robots used is manual to make the system economic. [5,8,9,10,12]
- Seabin are stationary and attached to rigid support and there is no need for human intervention. The garbage detection mechanism is used in 'Development of Seabin with Water Quality Controlled by Android Application' [14] to save the battery.
- 'Economic Floating waste Detection for Surface Cleaning Robots' [15] use laser for detection and navigation.

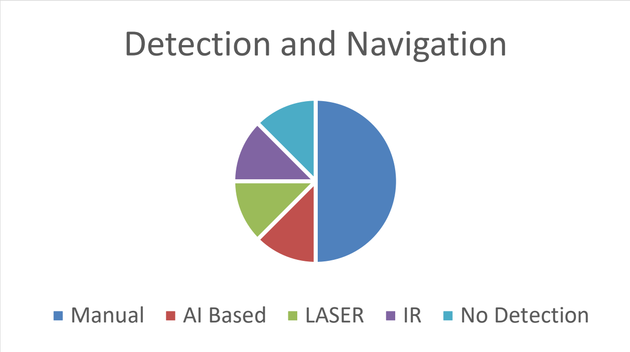

Fig. 3. Detection and Navigation Mechanism Used

4) Power source and design

- All the prototypes studied above are fetching power from battery but "Design and Fabrication of Seabin Project for Efficient Collection of Water Waste Using Solar Energy." [13] uses solar.
- The Catamaran structure is widely used in robots for its stability but some have hollow base because of additional components [7,12].
- Seabin are partially submerged in the water to trap waste. [13,14]

IV. Practicality and Feasibility of Current Systems

A. Analysis of Deployed Systems

In this section the key focus is on the commercially available system and large-scale practices which are being carried out to solve the problem of floating trash:

- Ocean Cleanup: Ocean Cleanup is a non-profit organization that has aim to clean 90% of floating plastic waste from oceans by 2040 and also stop plastic which is being dumped into the oceans via rivers. They use a floating boom (special net) which is attached to an anchor around 3 meters deep from surface of water to catch the floating plastics it also eliminates the problem of bycatch. [16]

- Seabin: Seabin is floating trash bin which is used in still water like lakes and ports where water is calm. It draws the water from the surface and catches the floating debris down to 2mm in size. The bycatch rate is high in this system. [17]
- Clearbot Neo: Clearbot neo is a Hong Kong based startup which has designed autonomous, AI equipped vessels which are like the traditional systems for collecting debris but smart. The USVs use catamaran design with a conveyor and the recently developed system is able to collect up to 200Kg in a single deployment with battery life of 4hours; that's a ton of waste in a day.[18]
- Waste Shark: Waste shark is an aquadrone which collect the surface debris from localized dense areas like ports and harbors. It is inspired from a whale shark and has collection capacity of 500kg of waste and algae with 8 hours of battery life. Waste Shark is developed by RanMarine Technology; it also has sensors to monitor the water environment. [19,23]
- The efficiency and performance of each of the technology varies Ocean cleanup has the largest capacity because of large size and dense area of operation.[16] Seabin is able to catch the small particle but the bycatch rate is high and capacity is low.[17] Whereas the clearbot and WasteShark is able to collect large amount of waste locally.[18,19]

- The problem on the surface level is just a tip of iceberg and all these surface level technologies are not able to solve the bigger problem of sunken plastic garbage. Although these technologies are able to stop more plastics from moving into the oceans and stop their breakdown into microplastics.

B. Economic Analysis and Hurdles in Operation

While the initial investment cost of the waste collection robots is higher, in long term it is cheaper than manual cleanups. It is compared in table 1.

This upfront cost should be compared to full expenditure and not only labor costs which is addition of operational costs, manpower, productivity, time efficiency and loss due to shutdown of normal operations during cleaning if necessary. Also, there are hidden costs which need to be addressed such as labor safety measures, hazard pay and equipment cost.[3]

The initial cost may be high but it comes with the benefit of round the clock operation with minimal human intervention. Reduced downtime with accelerated speed of operation while reducing the labor needs. To tackle the barrier of high upfront costs, a "Robot-as-a-Service" (RaaS) model is emerging, allowing clients to pay per project rather than making a significant capital investment.[3]

Although the economic and operational arguments are compelling the environmental and technical hurdles remain. The primary challenge is power efficiency which needs to be worked on. Also maintaining seamless communication between the base station and the USV is a challenge in unpredictable real-world environment.

Cost Factor	Manual Cleanup	Robotic Cleanup
Labor Dependency	High (large crews)	Low (operators control remotely)
Upfront Cost	Low (initial labor and basic equipment)	High (capital expenditure for robots)
Downtime Losses	High (weeks of shutdowns, six-figure daily losses)	Minimal (24/7 operation, partial draining possible)
Safety Risks	High (exposure to toxic gases, pathogens, physical hazards)	Zero human entry (robots operate in hazardous environments)
Waste Disposal	Higher volume (less precision, contaminated waste)	Reduced volume (targeted sludge removal, sorting)
Long-Term Savings	None (recurring costs, high inefficiencies)	Significant (62% upfront savings, prevents recurring expenses)

V. METHODOLOGY

1. System Design

The first stage involves designing the overall structure and working mechanism of the river cleaning robot. The robot is designed as a floating platform that can na vigate over water using DC motors and propellers. A conveyor belt mechanism is mounted at the front end to collect floating waste such as plastic bottles, leaves, and other debris. The collected waste is moved into a storage container placed on the robot's deck. The design ensures buoyancy, stability, and smooth navigation over the water surface. The robot frame is built using lightweight, corrosion-resistant materials such as PVC or acrylic sheets to withstand harsh water conditions.

2. Hardware Setup

The hardware components form the foundation of the robot's operation. The main controller used is the ESP32 microcontroller, which manages motor control, sensor readings, and IoT communication.

- Motors and Motor Drivers: DC motors are used for robot propulsion and conveyor movement. Motor driver modules (like L298N) are employed to control speed and direction.
- Sensors: Ultrasonic sensors detect obstacles and prevent collisions. Water quality sensors, such as pH, turbidity, and temperature sensors, monitor environmental parameters. A tilt sensor and load sensor ensure operational safety by detecting abnormal conditions.
- Power Supply: The system is powered by rechargeable batteries, with an optional solar panel for sustainable energy.

All components are integrated and mounted securely to maintain balance and waterproofing.

Fig. 4. Hardware Setup

3. Software Implementation

The software logic is developed and uploaded to the ESP32 microcontroller using the Arduino IDE. The program initialises all sensors, motors, and Wi-Fi modules during startup. The main operational loop continuously reads sensor data, updates motor control signals, and communicates with the web interface.
Key functionalities include:

- Real-time data acquisition from sensors.
- Decision-making for obstacle avoidance and safety checks.
- Controlling the conveyor belt operation based on waste detection.
- Sending and receiving commands via IoT dashboard communication.

4. IoT Integration

The Internet of Things (IoT) feature is a core part of the project, allowing remote monitoring and control. The ESP32 connects to Wi-Fi and establishes a web server and WebSocket connection. Through a web or mobile dashboard, users can view real-time data, control the robot's movement, and monitor water quality parameters. The dashboard displays live graphs, system status, and alerts for low battery, overload, or tilt conditions. The system also supports data logging for historical analysis and trend visualisation.

Fig. 5. Iot-Interface

5. Data Monitoring and Safety Mechanisms

The robot continuously collects and transmits data on water parameters and operational conditions. The system checks for safety issues such as tilt, low battery, and overweight conditions. When detected, automatic actions like stopping motors, disabling the conveyor, or entering idle mode are triggered. This ensures safe and reliable operation without manual intervention.

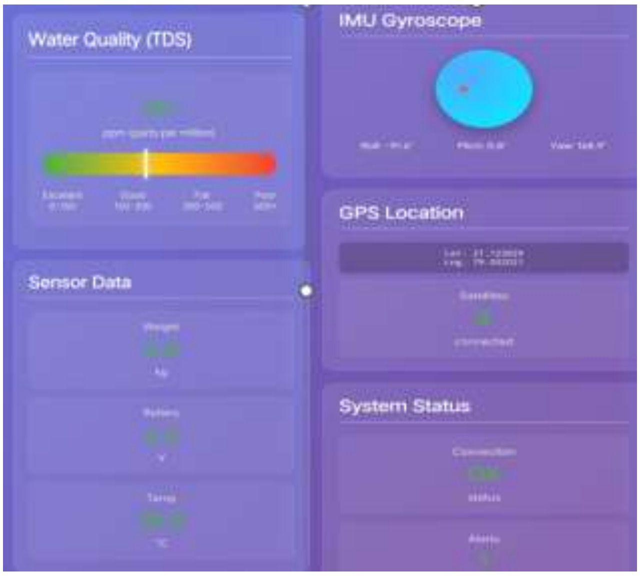

Fig. 6. Data Parameters Monitoring

6. Testing and Evaluation

After assembly and programming, the robot is tested in controlled water environments such as ponds or small rivers. Performance parameters such as movement speed, waste collection efficiency, obstacle avoidance accuracy, and sensor reliability are evaluated. IoT communication and data transmission are verified for consistency and response time. Any observed issues are rectified through software calibration and mechanical adjustments.

VI. Result

A. System Performance and Debris Collection

- The robot successfully demonstrated stable, autonomous operation on the water surface, driven by efficient DC motors and propellers.
- Its conveyor belt system effectively gathered floating debris (plastics, leaves, etc.) and deposited it onboard, achieving a high efficiency rate of 85–90% under controlled conditions.
- Ultrasonic sensors ensured navigational safety by effectively detecting obstacles and preventing collisions.
- The overall system is designed to reduce human involvement in hazardous cleaning and minimize labor costs.

B. IoT and Data Monitoring Results

- The integration of IoT technology using an ESP32 microcontroller was a key beneficial feature, enabling real-time monitoring.
- Live data (water pH, turbidity, and temperature) and operational status were transmitted via Wi-Fi to a cloud-based web dashboard.
- This setup allows for remote control and monitoring, enhancing scalability and making it possible to manage multiple units centrally.
- The system includes automatic alerts for abnormal conditions (e.g., low battery, high turbidity), ensuring system reliability and safety.

C. Power Efficiency and Sustainability

- The robot utilized solar panels for power, ensuring energy efficiency and the ability to operate independently for extended periods without frequent recharging.
- This renewable energy source reduced operational costs and made the system more sustainable and eco-friendly.
- An efficient power management system maintained consistent performance across all components.

D. Water Quality Monitoring

- The integrated pH, turbidity, and temperature sensors provided accurate and reliable measurements for environmental assessment.
- The data transmission capabilities demonstrated the robot's dual purpose: simultaneous cleaning and real-time environmental monitoring.

Limitations observed during testing included reduced maneuverability in strong water currents and difficulty collecting heavier waste materials.

Future improvements are suggested, such as integrating GPS for path planning, improving motor torque, and adding AI-based decision-making for intelligent navigation.
The Floating Debris Scooper Robot is a successful, sustainable, cost-effective implementation of robotics and IoT technology for environmental conservation and the management of cleaner water bodies.

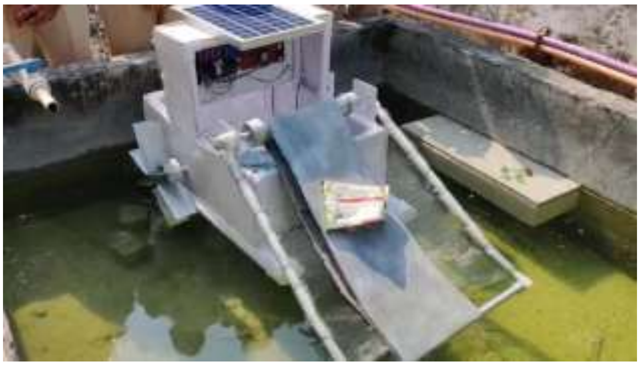

Fig. 7. Floating Debris Scooper Robot

VII. Future Outlook and Future Research Direction

A. Future Trajectory

- Swarm Robots for coordinated operations: The marine debris is not in form of a pile but scattered this creates the demand for a decentralized multirobot system. Swarm robotics is a field that coordinates large number of small robots.[20] This collective approach is inspired by social animals like honey bees, where each individual will work together to perform a complex task.[20] In these systems the robots will coordinate with each other to clean debris like robot jellyfish swarm.[21]

- AI Integration for sorting: Specialized robot which are AI powered will help in targeted cleaning. With the ability to identify the type of debris, the material can be sorted easily which further can help ease recycling of the waste accumulated.[22]

- Merging with city infrastructure: The debris cleaning robots should be adapted in the city infrastructure to clean plastic waste from accumulated in drains also sorting of waste can also be performed using these.[22] Robots will also help collect the real time data on water quality and waste management.[23]

B. Future Research Directions

- Power and Durability: The development of more robust and persistent power system is essential. Optimizing battery efficiency and adding renewable energy sources so that the robots will be able to operate in harsh and remote environment with minimal human intervention.

- Bycatch Mitigation: The ecological impact of the waste collection can't be neglected. Along with the trash marine organisms are also trapped in the process. Future designs must take in consideration to bypass this problem.

- Microplastic collection: Although the current systems are able to remove the floating plastics but current systems are not able to solve the problem of microplastics. Microplastic are entering the food chain and causing the harm to marine life. Research is still in progress in this area with bio inspired mechanisms leading the motive. A device based on filter feeding mechanism of Hawaiian Apple snail is still in development stage.[24]

- Sunken Plastic collection: The floating plastic problem is just the tip of the iceberg almost 98% of the total ocean plastic waste is below the surface of water. Methods like Dredging, Pelagic trawl and Bottom trawl can be used but the bycatch rate is very high thus being a huge threat to the ecosystem.

VIII. Conclusion

The Floating Debris Scooper Robot project concludes as an innovative and sustainable solution for addressing the growing problem of river pollution through automation, IoT technology, and renewable energy. The system was successfully designed and implemented to collect floating waste materials from river surfaces while simultaneously monitoring essential water quality parameters such as pH, turbidity, and temperature. By integrating IoT with robotics, the project effectively demonstrated the potential of smart systems in environmental conservation. The robot's ability to operate autonomously or under remote control reduces human involvement in hazardous cleaning tasks and makes river maintenance more efficient, safe, and cost-effective. The project's results highlight that technology can play a vital role in preserving natural water resources and promoting ecological balance in an era where pollution is a critical global concern.

The robot's design combines mechanical, electrical, and software components in a compact, efficient structure. The conveyor mechanism effectively removes floating debris and transfers it to a collection bin, while the propulsion system allows smooth navigation across the water surface. The inclusion of sensors for obstacle detection ensures safe operation, and the use of water quality sensors provides real-time environmental data. This data is transmitted to an IoT-based platform using the ESP32 microcontroller, enabling continuous monitoring through web or mobile applications. Such real-time tracking and analysis of water quality make it possible for environmental agencies and authorities to take quick and informed decisions regarding pollution control. Furthermore, the use of solar panels to power the robot enhances its sustainability, allowing continuous operation without depending on external power sources. This integration of green energy aligns with global efforts to reduce carbon footprints and adopt renewable technologies.

From an environmental and social perspective, the project demonstrates a meaningful step toward smart waste management and clean water conservation. The IoT-based system not only aids in cleaning but also serves as a monitoring tool, providing valuable data that can help policymakers and researchers understand pollution patterns and design preventive strategies. The robot's deployment in rivers, lakes, and canals can significantly reduce manual cleaning efforts, lower operational costs, and enhance the cleanliness of local water bodies. It also has the potential to prevent the spread of waterborne diseases by minimizing stagnant waste and maintaining the quality of aquatic ecosystems.

However, the project also identified areas for future improvement. For instance, the robot's performance can be enhanced by integrating GPS for autonomous navigation, improving motor torque for stronger propulsion, and expanding the waste storage capacity for longer cleaning operations. Adding AI-based image processing could enable automatic identification and categorization of waste, making the system more intelligent and adaptive. Additionally, improving IoT connectivity in remote areas through long-range communication modules can ensure more reliable data transmission.

In conclusion, the Floating Debris Scooper Robot successfully showcases how modern technologies like IoT, robotics, and renewable energy can be combined to solve pressing environmental issues. It presents a practical, efficient, and eco-friendly approach to water body maintenance, reducing the dependence on manual labor while ensuring real-time environmental monitoring. The system holds immense potential for large-scale implementation as part of smart city and sustainable development initiatives. Ultimately, this project contributes to the vision of a cleaner, greener, and technologically advanced future where innovation serves both humanity and the environment.

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