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DESIGN AND IMPLEMENTATION OF A SOLAR-ENERGIZED AUTONOMOUS ROBOTIC PLATFORM FOR AQUATIC POLLUTION MITIGATION

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Abstract: River cleaning robots have emerged as an effective solution for reducing floating waste and improving the quality of water bodies affected by increasing pollution. This paper presents the design and implementation of a Solar-Energized Autonomous Robotic Platform for Aquatic Pollution Mitigation. The proposed system is developed to collect floating debris such as plastic bottles, polythene bags, organic waste, and other pollutants from river surfaces with minimal human intervention. A solar energy module powers the robotic platform, ensuring sustainable and environmentally friendly operation while reducing dependence on conventional energy sources. The system integrates a microcontroller, DC motors, motor drivers, ultrasonic sensors, and a waste collection mechanism to enable navigation, obstacle detection, and efficient waste retrieval. Autonomous movement and real-time monitoring capabilities enhance operational efficiency and coverage. The developed platform contributes to cleaner waterways, supports environmental conservation efforts, and minimizes labor-intensive cleaning processes. Experimental evaluation demonstrates reliable performance in waste collection and navigation, highlighting the potential of solar-powered robotic technologies for sustainable aquatic pollution management in diverse water environments.

Index Terms –River Cleaning Robot, Solar Energy, Aquatic Pollution Mitigation, Autonomous Robotics, Waste Collection System, Water Surface Cleaning, Environmental Monitoring, Sustainable Technology

I. INTRODUCTION

Water resources play a vital role in maintaining ecological balance, supporting biodiversity, and fulfilling domestic, agricultural, and industrial requirements. Rapid urbanization, population growth, and improper waste disposal practices have significantly increased the amount of solid waste entering rivers, lakes, and other water bodies. Plastic bottles, packaging materials, organic debris, and various floating pollutants accumulate on water surfaces, causing environmental degradation, obstructing water flow, and threatening aquatic life. Conventional cleaning methods generally rely on manual labor, which is time-consuming, inefficient, costly, and often associated with safety risks in contaminated or deep-water environments.Advancements in automation, renewable energy technologies, and intelligent control systems have created opportunities for developing sustainable solutions for environmental protection. Autonomous and remotely operated robotic platforms are increasingly being adopted for tasks that are repetitive, hazardous, or difficult to perform manually. Such systems can improve operational efficiency while reducing human effort and exposure to polluted environments.River cleaning robots have emerged as a promising technological approach for addressing the growing challenge of water pollution. These robots are designed to navigate across water surfaces, detect floating waste, and collect debris using mechanical retrieval mechanisms. Integration of sensors and control units enables efficient movement, obstacle avoidance, and waste collection operations. When combined with renewable energy sources, robotic cleaning systems become more sustainable and suitable for long-duration deployment in aquatic environments.This study presents the design and implementation of a Solar-Energized Autonomous Robotic Platform for Aquatic Pollution Mitigation. The proposed system utilizes solar energy as the primary power source to operate motors, sensors, and control electronics while minimizing dependence on conventional electrical power. The platform incorporates a waste collection mechanism capable of retrieving floating pollutants from the water surface and storing them in a collection container for subsequent disposal. Ultrasonic sensing technology assists in obstacle detection and navigation, enhancing operational reliability and safety.The developed system aims to provide an environmentally friendly, cost-effective, and efficient solution for maintaining cleaner waterways. By integrating solar power, autonomous mobility, and waste collection capabilities into a single platform, the project contributes toward sustainable water resource management and supports ongoing efforts to reduce aquatic pollution and preserve ecological health for future generations worldwide.

II. Related Works

Article [1]"Autonomous Water Quality Monitoring and Water Surface Cleaning Using a Multi-Function Unmanned Surface Vehicle" by Hsiu-Chen Chang, Chao-Hsien Lee, and Chung-Hao Lin in 2021: This paper presents a multi-function unmanned surface vehicle designed for monitoring water quality and collecting floating waste. The system integrates navigation control, obstacle avoidance, water sampling, and cleaning functions into a single platform. Ultrasonic sensors and wireless communication modules are employed for real-time operation. A dedicated collection mechanism is used to retrieve debris from the water surface efficiently. Experimental evaluations demonstrate stable navigation and effective waste collection. The platform reduces manual labor requirements and improves monitoring efficiency. The study highlights the importance of autonomous systems in environmental conservation. The proposed solution contributes to sustainable management of aquatic resources.

Article [2]"SMURF: A Fully Autonomous Water Surface Cleaning Robot" by Jingxuan Zhu and Yifan Wang in 2022: This research introduces SMURF, an autonomous robotic platform developed for cleaning floating waste from water surfaces. The robot performs navigation, waste detection, path planning, and debris collection without human intervention. A coverage path planning algorithm is implemented to maximize cleaning efficiency in irregular water bodies. The system can operate in rivers, lakes, and coastal regions. Advanced navigation methods help avoid obstacles and optimize movement. Experimental results indicate reliable performance under various environmental conditions. The design emphasizes scalability and operational efficiency. The study demonstrates the practical application of robotics in aquatic pollution control.

Article [3]"A Floating-Waste-Detection Method for Unmanned Surface Vehicles Based on Vision Systems" by Y. Li and X. Wang in 2023: This paper focuses on detecting floating waste using computer vision techniques for autonomous cleaning robots. The proposed method employs image processing algorithms and visual sensors to identify debris on water surfaces. Detection information is used to guide robotic vehicles toward waste locations. The study evaluates multiple detection approaches under realistic aquatic conditions. Experimental testing confirms improved accuracy and reliability in identifying floating objects. The method minimizes dependence on manual monitoring. Results show that visual sensing significantly improves waste collection efficiency. The research contributes to the development of intelligent environmental monitoring systems.

Article [4]"An Autonomous Navigation System for an Unmanned Surface Vehicle for Plastic Waste Collection" by Piero Figueroa and Luis Marsano in 2023: This paper presents an autonomous navigation framework for collecting plastic waste from water bodies. The system enables an unmanned surface vehicle to identify, approach, and collect floating debris efficiently. Navigation algorithms improve route planning and movement accuracy. Sensors are incorporated for environmental perception and obstacle avoidance. Experimental results demonstrate successful waste collection under different operational conditions. The navigation strategy enhances efficiency while reducing energy consumption. The study emphasizes practical deployment in polluted waterways. The findings confirm the effectiveness of intelligent navigation systems for aquatic waste management.

Article [5]"Surface Water Cleaning Robot (SWCR) for Sustainable Environmental Management" by A. Sharma and R. Verma in 2024: This study presents a robotic system developed for collecting floating waste from rivers and lakes. The robot utilizes motorized propulsion and a mechanical collection mechanism for debris removal. Autonomous navigation allows efficient operation in aquatic environments. The design reduces labor-intensive cleaning processes and improves operational safety. Experimental testing confirms effective removal of floating waste and stable movement. The robot contributes to environmental sustainability by supporting cleaner water bodies. The proposed system offers an economical and practical pollution-control solution. Results indicate strong potential for large-scale implementation.

Article [6]"Research on Detection of Floating Objects in River and Lake Based on AI Intelligent Image Recognition" by Jingyu Zhang, Ao Xiang, Yu Cheng, Qin Yang, and Liyang Wang in 2024: This paper investigates artificial intelligence techniques for identifying floating objects in rivers and lakes. Deep learning models such as SSD, Faster-RCNN, and YOLOv5 are evaluated for waste detection. A complete image acquisition and processing framework is developed. Experimental analysis demonstrates improved detection accuracy and processing speed. The system supports real-time identification of waste materials.

Article [7]"Development of Garbage Collecting Robot for Marine Microplastics" by Masaya Uno and Hiroki Tanaka in 2024: This research focuses on the development of a robotic mechanism for collecting marine microplastics. The study examines collection techniques and robot mobility in aquatic environments. Experimental investigations analyze waste retrieval efficiency and operational performance. A specialized collection mechanism is designed to improve microplastic removal. Results demonstrate the feasibility of robotic systems for environmental cleanup applications.

Article [8]"Autonomous Surface Water Cleaning Robots" by M. Patel and S. Kumar in 2024: This paper presents an autonomous robot intended for cleaning floating waste from water bodies. The system integrates sensors, microcontrollers, and waste collection mechanisms. Autonomous movement enables continuous cleaning operations with minimal human intervention. The robot is designed to improve environmental sustainability and public hygiene. Experimental studies demonstrate efficient collection of plastic waste and floating debris. The platform provides a low-cost and scalable solution for pollution control. Results indicate improved cleaning efficiency compared to manual methods.

Article [9]"Optimizing Plastic Waste Collection in Water Bodies Using Heterogeneous Autonomous Surface Vehicles with Deep Reinforcement Learning" by Alejandro Mendoza Barrionuevo, Samuel Yanes Luis, Daniel Gutiérrez Reina, and Sergio L. Toral Marín in 2024: This paper introduces a deep reinforcement learning framework for coordinating multiple autonomous surface vehicles. The system employs separate scout and cleaner vehicles to maximize waste collection efficiency. Artificial intelligence enables cooperative decision-making among robotic agents. Different environmental scenarios are analyzed to evaluate system performance. Results show improved adaptability compared to conventional methods. The framework enhances coverage, collection effectiveness, and operational efficiency.

Article [10]"Comprehensive Review of Design and Development of Water Cleaning Mechanisms" by S. Karthikeyan and P. Ramesh in 2025: This review paper analyzes recent developments in water-cleaning technologies. Various robotic and mechanical systems designed for removing floating waste are discussed. The study compares collection mechanisms, navigation techniques, and energy sources. Solar-powered and autonomous systems receive particular attention due to sustainability benefits. Advantages and limitations of existing technologies are thoroughly evaluated.

Article [11]"Autonomous and Solar-Powered Surface Water Waste Cleaning Robot" by A. Reddy and K. Singh in 2025: This study presents a solar-powered robotic platform for collecting floating waste from water bodies. Renewable energy is utilized to power motors, sensors, and control electronics. The robot demonstrates stable movement and efficient debris collection. Testing includes plastic bottles, wrappers, and organic waste materials. Solar energy supports extended operational duration under suitable conditions. The system reduces dependence on external charging infrastructure.

Article [12]"Multi-Robot Aerial Soft Manipulator for Floating Litter Collection" by Antonio González-Morgado, Sander Smits, Guillermo Heredia, Anibal Ollero, Alexandre Krupa, François Chaumette, Fabien Spindler, Antonio Franchi, and Chiara Gabellieri in 2025: This paper proposes a novel aerial robotic system for collecting floating litter from water surfaces. Two aerial robots cooperate through a flexible rope-based manipulator. The system increases payload capacity and improves collection performance. Optimization-based planning algorithms are used to control rope movement and object retrieval. Outdoor experiments validate successful litter collection operations. The approach reduces manual intervention in difficult-to-access locations. Performance analysis demonstrates improved collection efficiency and operational flexibility.

III. Problem Stetement

Increasing levels of pollution in rivers, lakes, and other water bodies have become a major environmental concern due to the continuous accumulation of floating waste such as plastic bottles, polythene bags, food packaging, and organic debris. These pollutants obstruct water flow, degrade water quality, threaten aquatic ecosystems, and create health hazards for surrounding communities. Existing cleaning methods mainly depend on manual labor, which is time-consuming, inefficient, costly, and often unsafe in contaminated environments. Limited accessibility to certain water regions further reduces cleaning effectiveness. Therefore, an efficient, sustainable, and automated solution is required to continuously collect floating waste and reduce aquatic pollution with minimal human intervention.

IV. Objectives

The primary objective of this study is to develop a solar-energized autonomous robotic platform capable of collecting floating waste from rivers and other water bodies efficiently. The system aims to reduce aquatic pollution by removing plastic bottles, polythene bags, organic debris, and similar contaminants from the water surface. Another objective is to minimize human involvement in cleaning operations and improve safety during waste removal activities. The study also focuses on utilizing renewable solar energy for sustainable operation, implementing obstacle detection for reliable navigation, enhancing waste collection efficiency, and promoting environmentally friendly solutions for maintaining cleaner and healthier aquatic ecosystems.

V. Methodology

1)System Design and Planning:The development process begins with the design and planning of the robotic platform. Requirements related to waste collection, navigation, power management, and environmental conditions are analyzed. A floating structure is designed to ensure stability on the water surface while supporting all hardware components. The overall architecture is planned to achieve efficient and reliable operation.

2)Solar Energy Integration:A solar panel is incorporated to provide a renewable source of energy for the robotic system. The generated energy is stored in a rechargeable battery to ensure continuous operation during varying sunlight conditions. Power management circuits regulate the voltage supplied to different components. This approach reduces dependence on conventional energy sources and supports sustainable operation.

3)Hardware Implementation:The hardware system consists of a microcontroller, DC motors, motor drivers, ultrasonic sensors, solar panel, battery, and waste collection mechanism. These components are assembled and interconnected according to the system design. Proper placement of each component ensures balanced weight distribution and stable movement. Hardware integration forms the foundation of the robotic platform.

4)Navigation and Obstacle Detection:Ultrasonic sensors are used to detect obstacles present on the water surface. The sensor continuously monitors the surrounding environment and sends distance information to the controller. Based on the received data, the robot adjusts its movement to avoid collisions. This functionality improves safety and enables smooth navigation during cleaning operations.

5)Waste Collection Mechanism:A conveyor-based or collection-arm mechanism is installed at the front of the robot to gather floating waste. As the robot moves forward, debris is directed into a storage container.

The mechanism is designed to handle different types of floating pollutants such as plastic bottles, wrappers, and organic waste. Efficient collection improves overall cleaning performance.

6)Autonomous Control and Operation:The microcontroller acts as the central control unit of the system. It processes sensor data, controls motor movement, and manages waste collection operations. Decision-making algorithms enable autonomous navigation and cleaning activities. This reduces the need for constant human supervision and enhances operational efficiency.

7)Testing and Performance Evaluation:The developed prototype is tested under different operating conditions to evaluate its performance. Parameters such as navigation accuracy, waste collection efficiency, obstacle detection capability, and power utilization are analyzed. The obtained results are compared with expected outcomes to identify improvements. Performance evaluation validates the effectiveness of the proposed robotic platform.

VI. SYSTEM ARCHITECTURE

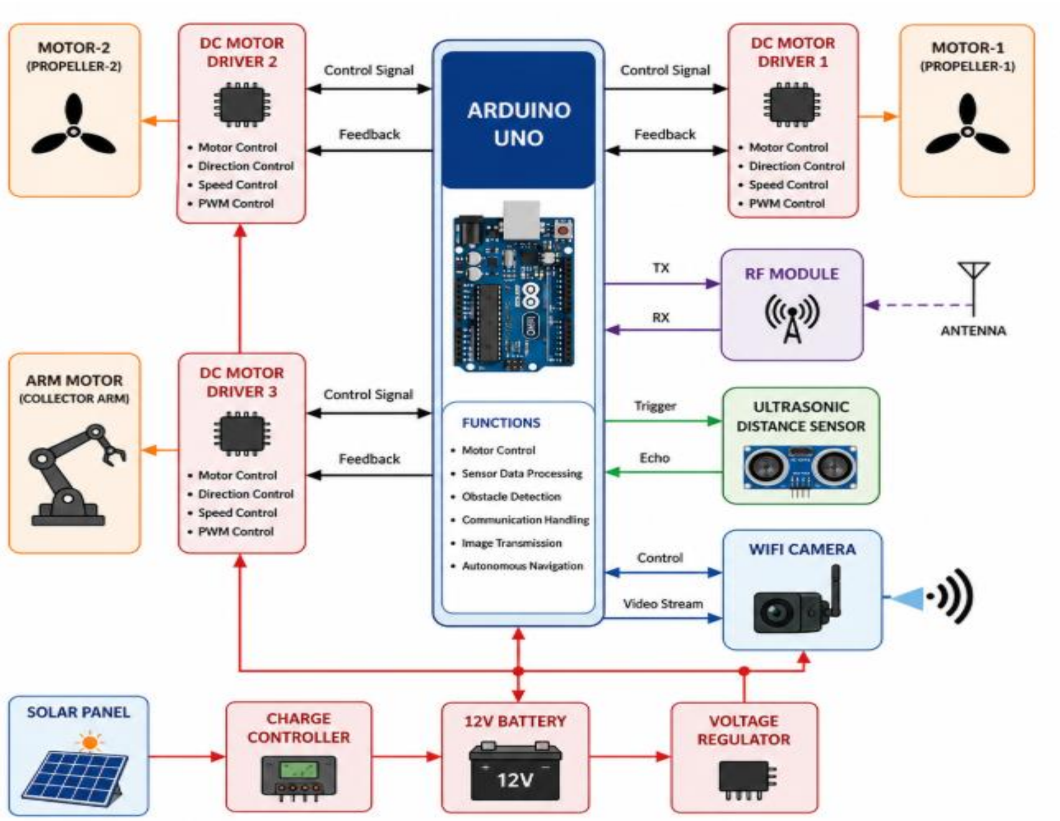

Fig 1: System Architecture of the Proposed Solar-Energized Autonomous Robotic Platform for Aquatic Pollution Mitigation

The system architecture illustrates the integration of hardware modules used in the proposed solar-energized autonomous robotic platform for aquatic pollution mitigation. The Arduino UNO functions as the central controller, coordinating communication between sensors, motors, and wireless modules. Three DC motor drivers are connected to the controller to operate two propulsion motors and a collector arm motor responsible for waste gathering. The RF module enables wireless communication and remote operation, while the WiFi camera provides real-time visual monitoring of the cleaning process. An ultrasonic distance sensor continuously detects nearby obstacles and supplies distance information to the controller for safe navigation. The power subsystem consists of a solar panel, charge controller, 12V battery, and voltage regulator, ensuring a stable and sustainable power supply for all components. Energy generated by the solar panel is stored in the battery and distributed to the entire system through the regulator. The coordinated operation of these modules enables efficient navigation, obstacle avoidance, waste collection, and environmental monitoring, making the platform suitable for autonomous aquatic cleaning applications.

VII. EXPERIMENTAL SETUP

Fig. 2: Prototype Implementation of the Solar-Powered Automated Electronic Waste Sorting System

The figure shows the fabricated prototype of the proposed river cleaning robot integrated with a solar panel, Arduino UNO, motor driver, battery, and waste collection mechanism

VIII. CONCLUSION AND FUTURE WORKS

In this research, a solar-energized autonomous robotic platform for aquatic pollution mitigation was successfully designed and implemented to collect floating waste from water surfaces. The system demonstrated effective navigation, obstacle detection, and waste collection while utilizing renewable solar energy for sustainable operation. Experimental evaluation confirmed reliable performance and reduced dependence on manual cleaning methods. Future work can focus on integrating artificial intelligence for waste classification, GPS-based autonomous navigation, enhanced collection capacity, real-time water quality monitoring, and improved communication systems. Additional optimization of energy management and large-scale deployment can further increase efficiency, coverage, and environmental impact in diverse aquatic environments worldwide.

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