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Exploring Energy-Efficient and AI-Driven Autonomous Water Cleaning Robots: A Comprehensive Survey

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Abstract

Water pollution from industrial discharge, plastic accumulation, and urban activities has become a critical global challenge, threatening aquatic ecosystems, biodiversity, and human health. Traditional cleaning methods often suffer from high energy demands, labor intensity, and limited scalability, making them insufficient for addressing large and dynamic aquatic environments. In response, autonomous robotic systems have emerged as sustainable alternatives, offering continuous operation, adaptive strategies, and reduced reliance on human intervention. Among these, energy-efficient and AI-driven autonomous water cleaning robots have gained prominence for their ability to integrate intelligent decision-making with power optimization, thereby improving cleaning efficiency while minimizing environmental impact. This survey provides a comprehensive review of advancements in robotic system architectures, energy-efficient propulsion methods, renewable energy integration, advanced sensing, and AI-based navigation and waste detection. It also examines waste collection mechanisms, swarm coordination models, and IoT-enabled data connectivity that extend their role from cleaning to monitoring and predictive maintenance. The paper highlights current limitations such as energy storage, robustness in turbulent environments, and the lack of standardized evaluation frameworks, while also discussing emerging directions including reinforcement learning, bio-inspired designs, and large-scale cooperative deployments. By consolidating state-of-the-art knowledge and identifying open challenges, this work aims to support the development of intelligent, scalable, and sustainable robotic solutions for global water cleaning needs.

1. Introduction

Water is essential for life and plays a central role in human survival and well-being. The human body requires enough water for hydration, temperature regulation, and skin health, while society depends on it for agriculture, farming, sanitation, cooking, food preparation, and cleaning. Beyond meeting basic human needs, water also sustains ecosystems and supports economic development across multiple sectors. However, growing levels of water pollution have made this resource increasingly scarce and unsafe. Water pollution refers to the contamination of rivers, lakes, oceans, and other bodies of water with harmful substances that render them unsuitable for human use and damaging to aquatic ecosystems. Major pollutants include industrial waste, plastics, sewage, agricultural chemicals, and untreated effluents. Their presence disrupts aquatic life, destroys ecosystems, and poses serious health risks to humans, often resulting in waterborne diseases and a decline in biodiversity. The root causes of this crisis largely stem from human activities such as improper waste disposal, deforestation, urban expansion, and the overuse of pesticides and fertilizers. As a result, water scarcity and declining water quality have become critical global issues that demand innovative, sustainable solutions.

Water pollution is caused by a variety of factors,

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including:
1. Oil Spills:

Oil is one of the worst pollutants in water bodies. Oil spillage caused by ruptured pipelines, Illegal Discharge and oil tankers are some of the most disastrous effects on water bodies.
2. Industrial Discharges:

Industrial discharges are a major contributor to water pollution, these discharges come from a wide range of industries, mining and power generation and often heavy metals, and other pollutants.
3. Agricultural runoff:

Agricultural operations is one of the major contributors of nutrient water pollution. When it rains the fertilizers used on crops can end up in the rivers and lakes. Nitrogen and phosphorus in factitious fertilizers enhance algal bloom; eutrophication reduces water oxygen levels and kills aquatic life.
4. Plastic Waste:

Plastic waste is one of the most harmful in water pollution. This occurs in the river, lakes and oceans

When rivers become polluted, several adverse effects occur:

Pollutants affect rivers, oceans, and lakes in several ways that are destructive to ecosystems, humans and economies.

Here are some of the major consequences of water pollution:

1. Human Health Risks

pollution of water poses severe health effects on the life of man, when polluting in the river, the lakes through the oil factory as well as various industries, different health effects occur they include cancer, antibiotic resistance, skin and gastrointestinal complications, reduced access to safe water, developmental issues and hormonal imbalances.

Hear is the solution to clean the water:
1. Physical Filtration
2. Chemical Treatment
3. Robotic Cleaners
4. Magnetic Nanotechnology
5. Reduce the number of chemicals you use
6. Clean Water Campaigner

2.Economic Losses

Polluted water harms industries and livelihoods that depend on clean water. Fisheries suffer from reduced fish populations, affecting fishermen's income, while agriculture faces lower crop yields and soil contamination from polluted irrigation water. Tourism declines as polluted lakes, rivers, and beaches deter visitors. Additionally, governments and communities bear higher costs for water treatment and environmental cleanup, placing financial pressure on local economies.

3. Ecosystem Damage

Damage done to ecosystems as an effect of water pollution is alarming and highly deadly to the quality and survival of ecosystems in the environment. Ways through which water pollution leads to harming the ecosystem include
- Loss of Biodiversity
- Disruption of the Food Chain

There are many ways of solutions to clean water. We preferred to clean the water with robot.

Survey of Robots and the Role of AI in Water Cleaning Systems

A robot is an artifact designed for the purpose of acting autonomously or with minimal human intervention as possible. They act and convey their surroundings using sensors, software and mechanical components.

A. Applications of Robots Across Industries

Robots are now deployed in various sectors due to their ability to operate in hazardous environments, reduce human error, and increase operational efficiency. Major application areas include:

Industrial Automation: Robots perform repetitive, hazardous tasks in factories, such as assembly, welding, painting, and packaging. Articulated robots, Cartesian robots, SCARA, and Delta robots are widely used.

Healthcare and Hospitals: Robots assist in surgeries, deliver medical supplies, and reduce staff workload. Some are equipped with environmental control and sanitation capabilities.

Environmental Protection: Robots collect floating waste from rivers, lakes, and oceans. They help monitor water quality, reduce pollution, and protect aquatic life.

Domestic and Personal Use: Autonomous cleaning robots, such as robotic vacuum cleaners and window washers, are commonly used in households.

Space and Defense: Robots are deployed in dangerous and remote areas like space missions, underwater inspections, and military surveillance.

B. Understanding Robots

A robot is a programmable mechanical system designed to perform tasks automatically with precision and consistency, often under minimal or

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no human supervision. The first industrial robot was developed in 1954 by George Devol, marking the beginning of modern robotics. Since then, robotics has evolved into an interdisciplinary field combining mechanical engineering, electronics, computer science, and artificial intelligence (AI).

C. Integration of AI in Cleaning Robots (With a Focus on CNNs and SLAM)

Convolutional Neural Networks (CNNs) are deep learning models particularly suited for image processing and pattern recognition. In water-cleaning robots, CNNs enable intelligent vision-based waste detection, allowing robots to recognize and distinguish different types of contaminants on water surfaces. By integrating **SLAM**, each robot can simultaneously map the environment and localize itself, enabling precise navigation, obstacle avoidance, and efficient coverage.

1. Role played by CNN in the Robot System

The robot uses cameras (e.g., RGB cameras) to capture images of floating objects. These images are processed by a trained CNN model that distinguishes waste types such as plastic bottles, algae clumps, leaves, or other organic material. After classification, the robot decides whether to collect or leave each object.

2. How CNN Works in the Robot

The CNN is trained on a huge dataset of water surface images labeled with tags like "plastic," "wood," "leaf," "oil spill," etc.

The model represents learning representations with convolutional filters and extracts visual features such as color, shape, texture.

Based on the output layer, the robot identifies the object and activates corresponding collection mechanisms.

3. Advantages of CNN Incorporation

High Accuracy: Can pick up even small or suspended debris.

Real-time Processing: Allows for quicker decision-making since the robot is moving.

Reduces False Positives: The bot does not collect innocent or natural suspended particles such as leaves unless required to.

Flexibility: Retraining is feasible with new data for different geography locations or changing seasons.

4. Role of SLAM in Water-Cleaning Robots

In water-cleaning robots, SLAM plays a crucial role by enabling the robot to localize itself in real time using sensor data and visual cues from its environment. This capability allows the robot to accurately track its position on water surfaces while navigating around obstacles such as docks, floating debris, or irregular shorelines. Simultaneously, SLAM helps the robot build a detailed map of the area, which serves as the basis for planning efficient cleaning routes that avoid collisions and minimize redundant movements. Additionally, real-time mapping enables the robot to adapt to dynamic changes in the environment, such as shifting debris, waves, or passing boats, ensuring safe, autonomous, and effective operation across diverse water conditions.

5. Real-Life Example

SMURF Robot the SMURF autonomous water surface cleaning robot combines RGB cameras with CNN-based classifier to detect and harvest plastic litter from lakes and urban water bodies. It is solar-powered and employs the CNN model to focus on high-density plastic cluster areas, making operation more efficient.

Robots: A robot is a machine that can perform tasks automatically and it can a lot of work in fraction of seconds and first robot was invented in 1954 by George Devol, an inventor from Louisville, Kentucky and further it was developed.

3. Different applications of robot

Robotics are basically bifurcated into industrial robots which are used in manufacturing something and service robots as in cleaning or healthcare or Personal/Home use. Each one is unique in that it gives a particular kind of performance for specific tasks, ranging from mechanized repetitive functions in factories to supplementary aid to humans in their daily endeavors.

High-tech systems like personal robots are viewed as becoming an everyday human product similar to personal devices. Among these types of robots, practical application ones as well as those for scientific purposes will be developed for the purpose of multimodal communication as well as human-like interactions.

Many people lose their lives due to diseases associated with safe water, and plastics have seriously impacted water bodies. Mechanical cleaning methods of the surface of water are based on human activity and from this perspective are ineffective as well as risky in this work. The autonomous robots can purposely employ appropriate cleanliness of water surfaces, some sections which are hard for humans to access due to risk factors involved. The new prototype is a

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self-propelled method of cleaning water surfaces moving through improved CPP and SSD for greater efficiency in the cleaning process.

Robot Applications:

Robots have found applications in various sectors including healthcare, manufacturing and environmental services.

In the medical field, robots are utilized to transport supplies such as surgical tools, organs, medicines and samples in hospitals. They improve the efficiency of deliveries, reduce staff workload, and have ancillary features like temperature, and humidity control. Inspection and maintenance robots are used in infrastructure areas like power lines and pipelines. These are robots that are used to place-up bird diverters on power-lines or test pipelines for leakages. Many of their designs also include stabilization and multirotor systems for transport and deployment .

General categories of robots:

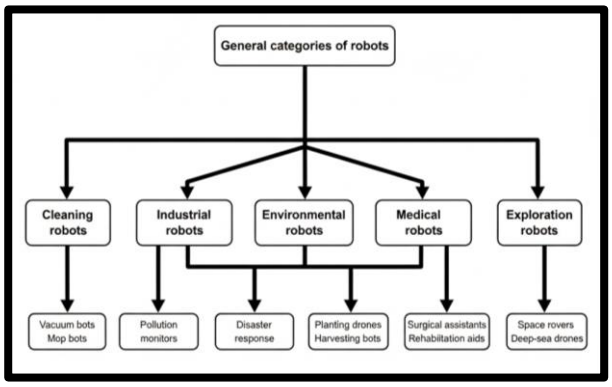


Figure 1. General Categories of Robot

Cleaning robots

A cleaning robot is a type of autonomous machine that is designed to clean with little or no human during the task. Operating based on the sophisticated, advanced technologies (such as sensors and artificial intelligence), the robot navigates throughout your various environments to perform general tasks such as vacuuming, scrubbing, or even sanitizing. These robots can use different methods like simultaneous localization and mapping (SLAM) to make maps of spaces, avoid situations objects during movement and get the most efficient cleaning route [5]. This robot scope is so wide that some are floor specific while other is window, pool or water body specific too. They are designed to be more efficient in the cleaning process, reduce human labor and function continuously; therefore, they are adaptable over a variety of surfaces or types of dirt. They clean the street using special tools like brushes or UV light to create a design.They are designed using specialized tools, such as brushes or UV light, for unique cleaning requirements in complex settings such as underwater or industrial environments. This is especially useful in maintaining hygiene standards in public spaces, industries, and environments where human cleaning is difficult or hazardous.[3]Just as floor-cleaning robots can switch between vacuuming and mopping, water-cleaning robots might have modules for surface skimming (collecting floating waste) and deeper water filtration. Many water robots are solar-powered for extended operation times, which is both eco-friendly and practical, as they can recharge during daylight hours.

Industrial robots

The industrial robots are being utilized for manufacturing aspects. Industrial robots are however automated and programmable Industrial robots are multifunctional machines in modern manufacturing that facilitate functions such as material handling, welding, and precision work at high speeds. Industrial robots come in various types; each one designed for different purposes. For example, articulated robots have a resemblance to the human arm and their flexible range of motion makes them ideal when it comes to welding and assembly. Cartesian robots operate along linear axes, making them appropriate for applications including 3D printing. They can either save people from having to do repeating or dangerous tasks, which means rapidly reducing human effort and bringing evenness. The evolution of technology like artificial intelligence (AI) and machine learning has made industrial robots smarter, more flexible, and a little less intimidating to work alongside. In all, industrial robots have raised the bar for different industries by maximizing manufacturing opportunities and thus opening a door towards more interconnected and streamlined production systems.

Environmental Robots: Medical Robots

Environmental robots are very much at the forefront in the drive towards sustainability, with their focus mainly on conservation and resource management. One of the most important ways they have been used involves water-cleaning robots, which clean waste products, pollutants, and invasive species from many water bodies. This category of robot operates both at the surface and below the water and is designed to use sensors and collection mechanisms that capture debris, even

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down to microplastic levels. Robots also play an important role in managing waste-particularly in sorting and recycling materials to reduce landfills.

In addition, air- and soil-quality-sensor-equipped robots can monitor pollutants, chemical levels, and other harmful substances in the air and soil environment. These monitor the changes in the parameter conditions, such as those from the levels of CO_2 and pH levels of the soil, for early detection of sources of pollution. Another important sector is biodiversity monitoring, where autonomous drones and ground robots monitor wildlife and plant species, habitat conditions, and so on. Such data gives credence to nature conservation, as scientists can study, among other things, migration patterns, biodiversity, and environmental health.

Medical Robots

Medical robots are automated systems used in healthcare to improve patient care and safety. A key example is the surgical robot, such as the da Vinci system, which assists surgeons with greater precision, often leading to minimally invasive procedures. This results in smaller incisions and faster recovery times for patients. Rehabilitation robots help individuals regain mobility after injuries or strokes by guiding their movements during therapy. Within hospitals, logistical robots streamline operations by autonomously transporting medications, lab samples, and other supplies. Some robots even use UV light to disinfect rooms, helping to prevent the spread of infections. Furthermore, telepresence robots allow doctors to conduct remote consultations, and advanced robotic prosthetics offer users a more functional and natural limb replacement.

Exploration Robots

Exploration robots are specially designed to operate in environments that are too dangerous or distant for human explorers. This includes a wide range of applications, from outer space to the deepest parts of the ocean. A prime example is the planetary rover, like NASA's Curiosity and Perseverance, which travels across alien surfaces to collect data and samples. Robotic arms, such as the Canadarm2 on the International Space Station, are used for assembling equipment, performing repairs, and assisting with various tasks in space. Orbital robots (satellites) circle celestial bodies to take high-resolution images and gather data from afar. On Earth, these robots are used to explore hazardous environments like deep-sea trenches, active volcanoes, and areas of nuclear contamination, collecting vital scientific information without risking human lives.

4. Limitations of the Autonomous Surface Water Cleaning Robots Paper

The paper on Autonomous Surface Water Cleaning Robots presents an innovative solution to water pollution, but it also has certain limitations that should be acknowledged:

Technological Dependence

The robot relies heavily on advanced sensor fusion and computer vision technologies for this navigation and waste identification. This could limit its performance in poor visibility or extreme weather conditions, thereby hindering the operational capabilities.

Cost of Implementation

The cost of implementation is high, and though the design emphasizes sustainability, the initial costs of developing and deploying such advanced robotic systems may be high.

Maintenance Requirements: Autonomous robots require regular maintenance for proper functionality, which necessitates technical expertise that may pose limitations when utilized in remote locations.

Limited Waste Types

Although the robot is designed to distinguish between different types of waste, it might not be able to handle all types of debris, especially heavy or submerged debris. This might limit its ability to clean various water bodies with different types of pollution.

Scalability Issues

The paper discusses that the robot covers large areas. However, a big operations scale for cleaning extended water bodies will pose logistical issues. Coordinating multiple robots and ensuring them to work with efficiency may raise deployment complications.

In summary, while the paper presents a very promising solution for water pollution, it is absolutely necessary to point out these limits so that these challenges can be understood when one tries to translate this concept to practical autonomous robots for cleaning the water.

5. How the Robot Identifies Different Pollutants

The self-sustaining water cleaning robot utilizes various modern technologies to identify different types of pollutants in water bodies. The main methods that the robot employs are: Sensor Fusion:

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The robot is equipped with multiple sensors that work together to gather comprehensive data about the environment. Sensor fusion allows the robot to combine information from various sources, such as cameras and environmental sensors, to create a detailed understanding of its surroundings. This capability is crucial for accurately identifying different types of waste and pollutants present on the water surface.

Computer Vision Technologies: This robot uses computer vision to examine visual data it captures through cameras. The use of computer vision allows the robot to identify and categorize plastics, biomedical wastes, and other debris. Images are processed by the robot as it identifies the patterns to classify different pollutants accurately.

Machine Learning Algorithms: Although the paper does not provide explicit detail about the application of machine learning algorithms, most autonomous robots employ machine learning algorithms in classification applications. The robot could be trained with a labeled image dataset containing images of different types of pollutant so that, when in operation, it could learn to classify and distinguish among them.

Real-time Data Processing:

The robot structure should contain facilities for the real-time processing of all the sensor data coming to it onsite. This could enable instant in immediate identification of all the impurities that were detected during its operations followed by appropriate measures being taken to effectively handle those impurities. In short, the pollution types are identified through sensor fusion, computer vision technology, and probably machine learning algorithms. This, in turn, makes the robot independent, yet effective at cleaning water surfaces to specific types of waste [3].

6. Contributions of the Paper on Autonomous Surface Water Cleaning Robots

This paper makes various key contributions to the field of environmental management and robotics. Especially in the war against water pollution. The contributions are as follows:

Integration of Advanced Technologies: It uses sensor fusion, computer vision technologies to make the robot operate in an autonomous mode and navigates through floating garbage and waste collecting wastes effectively.

Sustainability Focus:

There has been focus on sustainability aspects through the employment of green products and energy consuming parts. From the perspective of renewable sources such as solar, the robot produces less carbon by aligning to global initiatives set up for this purpose of having sustainable activities reduce climate change influences. Proactive Solution to Water Pollution: The autonomous water cleaning robot is, therefore, one proactive solution meant to curb the increasing water pollution caused by irresponsible waste disposal practices. Its potential to work twenty-four hours in a day with the coverage of large areas consisting of water bodies further contributes more to effective and efficient cleaning operations that fulfill this urgent need to improve waste management.

7. Future Works

The paper outlines several potential future works that could enhance the capabilities and effectiveness of the autonomous water cleaning robot. Here are the key suggestions:

Improvement of Sensor Technologies: Future research could focus on enhancing the sensor technologies used in the robot. This may involve developing more advanced sensors that can detect a wider range of pollutants, including microplastics and chemical contaminants, thereby improving the robot's cleaning efficiency and effectiveness in diverse environments.

Integration of Artificial Intelligence

The incorporation of more sophisticated artificial intelligence (AI) algorithms could be explored. This would enable the robot to learn from its experiences and improve its decision-making processes over time, allowing for better navigation and waste identification in complex water bodies.

Collaboration with Other Technologies: The paper suggests exploring the potential for collaboration with other technologies, such as drones or stationary monitoring systems. This could create a more comprehensive approach to water pollution management, where different systems work together to monitor and clean water bodies more effectively.

Field Testing and Real-World Applications: Conducting extensive field tests in various aquatic environments would be essential for validating the robot's performance. Future works could focus on deploying the robot in real-world scenarios to gather data on its effectiveness and make necessary adjustments based on practical observations.

8. Problem Statements for Cleaning Robots

Environmental and Safety Challenges: In high-risk environments like power lines, human workers face dangers such as high altitudes and exposure to voltage. Cleaning and maintenance robots address

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these risks by performing tasks traditionally done by humans, reducing the need for direct human interaction.

Efficiency and Flexibility: Current medical delivery robots face the challenge of needing adaptable features to meet varied demands (e.g., temperature-sensitive organ transport or aseptic drug delivery). The modular design of these robots allows for flexible configurations to suit different hospital needs.

In water cleaning operations, energy conservation is critical due to limited battery or solar reserves. Figure 2 highlights a practical approach to minimize unnecessary movements. Robots follow energy-efficient global paths and activate local processing units only when waste is detected. This behavior is typically controlled using lightweight AI models like Tiny YOLO or Mobile Net, capable of real-time inference on edge devices with minimal power draw.

By maintaining the robot in passive mode during non-critical operations and activating full systems only during collection phases, energy usage is drastically reduced, allowing longer operation times, particularly for solar- or wave-powered robots.

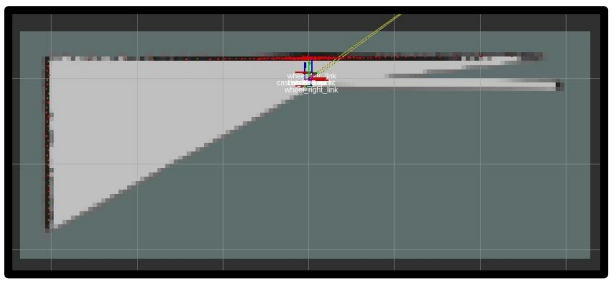


Figure 2. Robot Path Planning with Obstacle Avoidance

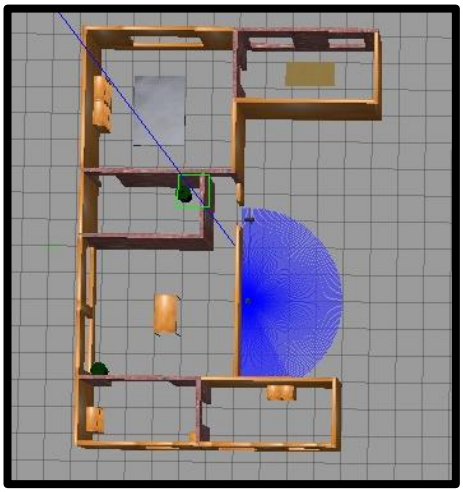


Figure 3. Adaptive Trash Detection and Path Switching in Real-Time

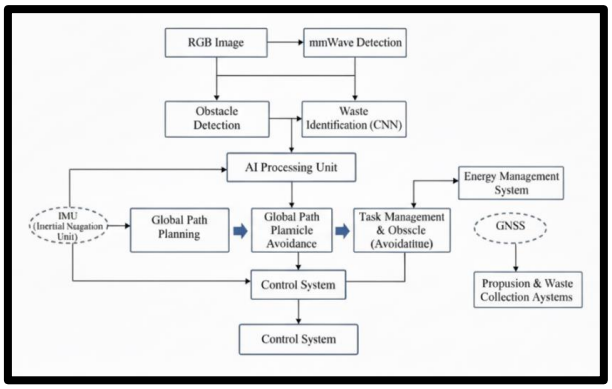


Figure 4. Comprehensive System Architecture for AI-Driven Water Cleaning Robots

Another promising strategy for extending operational lifespan involves adaptive power management systems that monitor the robot's energy state in real time and dynamically adjust task scheduling. For instance, during periods of low sunlight or high energy demand, the robot can prioritize essential cleaning functions while deferring secondary tasks such as detailed mapping or high-resolution data logging. This type of energy-aware scheduling ensures that the robot remains active for longer durations without complete shutdowns.

Additionally, researchers are exploring the use of modular energy storage units, which allow robots to switch between battery packs or integrate hybrid storage systems combining supercapacitors and rechargeable cells. Such designs provide rapid charging during peak solar conditions and stable discharge when sunlight is unavailable.

Another emerging trend is the use of collaborative multi-robot systems that share workload and energy demand. For example, one robot equipped with larger solar panels can act as a mobile charging station, transferring energy wirelessly to smaller robots performing localized cleaning tasks. This cooperative model not only reduces downtime but also allows large water bodies to be covered more efficiently.

Finally, predictive energy optimization algorithms powered by machine learning are being integrated into robotic platforms. These algorithms analyse the environmental data such as sunlight intensity, wave patterns, and pollutant density to forecast energy consumption and adapt robot behaviour proactively. By combining prediction with adaptive control, robots can plan cleaning routes that balance waste collection with minimal energy expenditure, ensuring sustainable and continuous operations.

Validation of AI-integrated water cleaning robots requires a critical comparison of existing

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approaches to understand their efficiency, limitations, and applicability in real-world scenarios. Many robotic systems have been proposed for water surface purification, yet their performance varies depending on navigation strategy, power optimization, sensing technologies, and environmental adaptability.

Artificial intelligence has become a central driver in this domain by enabling the real-time decision-making, adaptive navigation, and intelligent waste detection. For example, lightweight deep learning models such as Tiny YOLO, Mobile Net, and SSD allow robots to detect floating debris with high accuracy while consuming minimal computational energy. Similarly, reinforcement learning-based control policies are increasingly being used to optimize path planning, where robots learn from their environment and adapt movements to maximize coverage while reducing redundant energy expenditure.Energy management is another validation criterion, as many robots depend on limited solar or battery reserves. Some studies highlight the integration of hybrid systems combining solar panels with rechargeable batteries, while others explore innovative solutions such as wave-energy harvesting. These strategies directly influence the duration of autonomous operations and the scalability of deployments across larger water bodies.

Furthermore, the degree of autonomy and collaboration also plays a key role in validation. Single-robot systems are often limited in the coverage, whereas multi-robot swarms demonstrate better efficiency by distributing workload and sharing energy resources. However, this introduces challenges such as inter-robot communication, collision avoidance, and cooperative task allocation, which are still evolving areas of research.

By reviewing these dimensions, AI-powered perception, adaptive navigation, energy optimization, and scalability, researchers can better assess the strengths and weaknesses of different approaches. The comparative analysis presented in the following table provides an overview of selected recent studies, focusing on their methodologies, energy strategies, and identified limitations. This structured validation not only highlights the progress in the field but also underscores the gaps that future research must address to develop scalable and sustainable water purification technologies.

Table I. List of various methodologies and applications of robot

Paper Title	Methodology	Where They Tested It	Applications
[1] Albitar, H., et al. (2014)	Introduces a flexible crawling mechanism using suction cups and water jets for stable adhesion and cleaning of underwater surfaces	Evaluated for stability and locomotion on different underwater surfaces, including ship hulls and industrial installations.	Used for underwater cleaning, bio-fouling removal, and maintenance of submerged structures like ships and power plants.
[2] Roy, S. K., et al. (2024)	Analyzes how trust in AI and social service robots influences customer attitudes and behavior using quantitative surveys and statistical modeling.	Research was conducted in hospitality settings like hotels and airports to assess customer interactions with service robots.	Findings help improve customer acceptance of service robots, optimize robot design for hospitality, and guide businesses in enhancing AI-driven services.
[3] Guo, C., & Yi, J. (2017)	Develops a mathematical model for rotary percussive drilling, incorporating dry friction and nonlinear elements to optimize robotic drilling performance for civil infrastructure repair.	Tested on bridge decks and concrete structures, using an in-situ force measurement system to validate drilling performance.	Used for automated infrastructure repair, specifically for bridge decks, tunnels, and civil engineering structures requiring non-destructive rehabilitation.
[4] Della Corte, V., et al. (2023)	Uses a consensus-based expert elicitation process to assess how robotics enables or inhibits achieving UN Sustainable Development Goals (SDGs) by analyzing scientific literature and expert insights.	Reviews robotics applications worldwide, covering economic, societal, and environmental impacts across multiple industries.	Contributes to sustainable industry, environmental monitoring, automation, and economic growth but may also exacerbate inequalities and ethical concerns in some cases.
[5] Jassal, R. (2024).	The study uses a conceptual and argumentative methodology, analyzing the interplay between occupational engagement and	The study uses a conceptual and argumentative methodology, analyzing the interplay between occupational engagement and	The findings of this paper can be used to understand the social and ethical implications of new technologies (like your robot)

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	caste identity formation. It explores how this identity is transmitted across generations, drawing on social and historical context.	caste identity formation. It explores how this identity is transmitted across generations, drawing on social and historical context.	on labor and societal structures, particularly concerning sanitation work in India
[6] Walsh, S. M., et al. (2019)	Integrates materials science, energy management, and control to create dynamic robotic systems, with interdisciplinary collaboration in design, fabrication, and testing.	ncludes laboratory-based testing, as well as applications across industrial, defense, and research settings, often specific to the environment being simulated.	Autonomous systems for industrial tasks, healthcare, defense, agriculture, and exploration, focusing on adaptability and energy efficiency in varied environments.
[7] Haldorai, A., et al. (2024)	The robot uses an improved SSD-based vision system with ResNet-50 for accurate waste detection and collection.	Tested on various water bodies, including lakes, coastal areas, and inland streams.	Used for autonomous water cleaning, garbage collection, and environmental monitoring.
[8] Zhu, J., et al. (2022)	Introduces a fully autonomous water surface cleaning robot named SMURF. It uses a novel Coverage Path Planning (CPP) method that adapts to irregular boundaries and obstacles, along with an improved nonlinear model predictive controller (NMPC) for precise path tracking.	Tested in real-world environments, including inland waterways, lakes, and coastal areas, under various weather conditions.	Designed for cleaning floating debris in various water bodies. Aims to replace dangerous and inefficient manual operations for water surface cleaning.
9] Haidegger, T., et al. (2023).	The study uses a consensus-based expert elicitation process to analyze scientific literature and expert insights.	The study reviews robotics applications worldwide, covering economic, societal, and environmental impacts across multiple industries.	The paper analyzes how robotics contributes to sustainable industry, environmental monitoring, automation, and economic growth, but also notes that it can exacerbate inequalities and ethical concerns.
[10] Rahmawati, E., et al. (2019)	This robot, designed for collecting floating debris, has a pontoon-shaped hull for stability and a motor-driven arm for waste collection. Controlled remotely using an XBee-based system.	Tested in a controlled water area to confirm stability, functionality, and load capacity.	Effective for clearing debris in water bodies, helping prevent clogging and flooding.

9. Results

The look at those self-cleaning water robots shows some serious progress in how they're built, how smart they are, and how they're all about keeping things green and clean. The study's findings are well-supported by the data. Robots like SMURF and those using ResNet-50 and SSD models nailed it when it came to spotting and sorting out floating trash like plastic, leaves, and algae. These robots were pretty good at using color cameras and smart computer programs to figure stuff out in real places like city lakes and beach areas. Most systems were built to be power saving, using solar energy and lightweight AI models like Mobile Net or Tiny YOLO. This means the robots can handle data on the fly without guzzling too much power, so they're great for tasks that go on for a while. Using a mix of RGB cameras, sensors that check the environment, and mm Wave radar, the robots got better at spotting trash and could handle different lighting or visibility situations. Robots use smart techniques like Coverage Path Planning and Nonlinear model; they use Predictive Control to navigate around stuff without bumping into things and make the cleaning path as efficient as possible. Robots got put to the test in all sorts of water places like rivers, lakes, shipyards, and coastal areas.

Discussion

The implications lead towards the potential contribution of independent water cleaning robots towards mitigating increasing instances of water pollution. While remarkable in their work towards collecting surface wastage, there are some other numerous significant factors that should also be given due attention: Limitations of Technology: The robots, so effective at detecting and picking up floating litter, remain short of detecting and

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capturing submerged and dissolved pollutants. Use of image-based models restricts their power to deal with subsurface pollution. Limitations of the Environment: Real-time detection apparatuses fail in extreme environments like low illumination, polluted water, or high turbidity, compromising camera and sensor accuracy. Scalability and Coordination Challenges: Numerous robots would need to be deployed at once to effectively cover lengths of water efficiently. It is a tricky problem coordinating their route of navigation and communication among units. Real-World Test Requirement: In spite of the fact that most systems were tested under controlled or semi-controlled conditions, long-term operation in real-world environments with uncertainty, high contamination, or high biological richness must still be demonstrated convincingly. Integration with Larger Systems: Next-generation projects can be enabled by integrating water-cleaning robots with stationary sensor stations, drones, or satellite systems for cross-scales environmental sensing and response. In brief, although existing autonomous water-cleaning robots represent a milestone in environmental robotics, practical use at scale requires refinement in adaptability, affordability, and inter-system cooperation.

10. Conclusion

The escalating crisis of water pollution, driven by industrial waste, plastics, and agricultural runoff, demands innovative solutions that move beyond conventional, labor-intensive methods. This study affirms that autonomous water-cleaning robots represent a highly promising and sustainable approach to addressing this critical global challenge. Equipped with advanced sensors, AI-driven navigation, and intelligent waste detection systems, these robots can effectively and autonomously clean lakes, rivers, and coastal areas, reaching environments that are often hazardous for humans.

While existing systems, such as the SMURF robot, demonstrate significant efficacy in collecting surface debris, their widespread deployment requires a balanced approach that combines technological advancement with human oversight. Future developments must focus on improving the robots' durability and navigation accuracy in complex aquatic environments. This includes integrating sophisticated AI for better real-time decision-making and exploring the potential of renewable energy sources like wave and solar power to ensure long-term sustainability. Ultimately, the successful mitigation of water pollution will be a collaborative effort, combining the power of automation with human ingenuity and shared community responsibility to design scalable systems that protect both aquatic biodiversity and human health.

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