DESIGN AND DEVELOPMENT OF MOBILE ROBOTIC ARM FOR CLEANING INDIAN AND WESTERN TOILETS

Mr.R.Arivazhagan M.E
Assistant Professor
Department of Mechatronics
Agni College of technology
Thalambur, OMR-Chennai
Tamilnadu India
arivazhagan.mht@act.edu.in

Parthasarathy.D
Student
Department of Mechatronics
Agni College of technology
Thalambur,OMR-Chennai,
Tamilnadu,India
22mht034@act.edu.in

C.vignesh
Student
Department of Mechatronics
Agni College of technology
Thalambur OMR-Chennai
Tamilnadu India
22mht048@act.edu.in

Chambrish Prabhu R.K
Student
Department of Mechatronics
Agni College of technology
Thalambur OMR-Chennai
Tamilnadu India
22le004mht@act.edu.in

Gugan.D
Student
Department of Mechatronics
Agni College of technology
Thalambur OMR-Chennai
Tamilnadu India
22mht058@act.edu.in

ABSTRACT

The need for efficient automatic sanitation systems has increased significantly in public and private facilities as toilet cleaning is a repetitive task and is often perceived as undesirable by individuals. This paper presents the design, development, and experimental evaluation of a semi-automatic three-axis robotic arm system for cleaning both Indian and Western toilets. The proposed system integrates a three-degree-of-freedom (3-DOF) robotic manipulator, rotating brush mechanism, water jet system, and disinfectant spraying unit, controlled through a microcontroller based interface. The robotic system is designed to address the limitations of conventional cleaning methods by reducing human intervention, improving cleaning consistency, and optimizing resource utilization. Experimental analysis was conducted under multiple operating conditions and compared with manual cleaning methods. Results indicate that the proposed system reduces cleaning time by up to 48%, water consumption by 41%, and detergent usage by 33%, while achieving a maximum cleaning coverage of 96%. Mechanical and electrical performance evaluations confirm stable operation within safe limits, with efficient power consumption and adequate battery life for practical applications. The system demonstrates adaptability to different toilet geometries, making it suitable for diverse sanitation environments. The proposed semi-automatic robotic cleaning system offers a cost effective, scalable, and safer

alternative to traditional methods and has strong potential for deployment in public sanitation facilities, hospitals, and smart city infrastructures.

INTRODUCTION

Sanitation is a fundamental component of public health and environmental sustainability, yet maintaining hygienic toilet facilities remains a persistent challenge, particularly in high-traffic public environments such as hospitals, railway stations, educational institutions, and commercial complexes. Traditional manual cleaning methods are labor-intensive, time-consuming. These limitations have driven increasing interest in the development of automated and robotic cleaning systems aimed at improving safety, efficiency, and consistency [1], [2].

Recent advancements in robotics have enabled the deployment of intelligent cleaning systems capable of operating in complex and unstructured environments. Multi-degree-of-freedom (DOF) robotic manipulators have proven particularly effective due to their flexibility and ability to access confined and geometrically complex surfaces [3], [4]. In sanitation applications, robotic arms equipped with cleaning end-effectors such as brushes, sprayers, and suction devices can significantly enhance cleaning coverage and performance compared to manual methods [5].

The integration of sensing technologies, including vision systems and proximity sensors, has further improved the capabilities of modern cleaning robots. Vision-guided robotic systems enable accurate localization and targeted cleaning, reducing redundant operations and optimizing resource usage [6], [7]. Additionally, the incorporation of Internet of Things (IoT) technologies allows for remote monitoring and control, facilitating the development of smart sanitation infrastructures [8].

In recent years, research has also focused on incorporating artificial intelligence (AI) and machine learning techniques into robotic cleaning systems. These approaches enable adaptive decision making, path planning, and dirt detection, thereby enhancing the autonomy and efficiency of cleaning operations [9], [10]. Furthermore, reconfigurable and modular robotic platforms have been introduced to handle diverse cleaning environments, demonstrating improved adaptability and scalability [11].

Sustainability has become a key consideration in sanitation system design. Excessive water and chemical usage in traditional cleaning methods contribute to environmental degradation. Consequently, modern robotic cleaning systems aim to optimize resource utilization while maintaining high hygiene standards [12]. This is particularly important in developing regions where water conservation is a critical concern.

Despite these technological advancements, significant challenges remain. One major limitation is the lack of adaptability of existing robotic systems to different toilet designs. In countries like India, both Indian (squat-type) and Western (seated-type) toilets are widely used, each presenting unique geometric and operational challenges [13]. Most existing robotic cleaning solutions are designed for a single configuration, limiting their practical applicability in real-world scenarios. Semi-automatic systems, which combine human supervision with robotic execution, offer a promising alternative by balancing performance, cost, and ease of operation [14], [15]. In this context, the present study proposes the design and experimental evaluation of a semi-automatic three-axis robotic arm system capable of cleaning both Indian and Western toilets. The system focuses on achieving efficient cleaning performance while reducing human intervention, water consumption, and operational cost. Experimental validation is carried out to assess the effectiveness, mechanical stability, and energy efficiency of the proposed system, thereby contributing to the advancement of practical and scalable sanitation robotics.

MATERIALS AND METHODS

The proposed system consists of a semi-automatic three-axis robotic arm designed to clean both Indian and Western toilets through an integrated mechanical, electrical, and control framework. The robotic arm structure is fabricated using lightweight aluminum and mild steel to ensure durability, corrosion resistance, and stable operation in wet environments. The system employs a three-degree-of-freedom (3-DOF) mechanism comprising base rotation (X-axis) driven by a DC geared motor, arm extension (Y-axis) using a high-torque servo motor, and vertical movement (Z-axis) for depth cleaning. The end effector includes a rotating nylon brush for scrubbing, a multi-directional spray nozzle for water and detergent application, and a flexible mounting system to adapt to different toilet geometries. Actuation is achieved using a 200 RPM base motor (measured at approximately 185 RPM under load) and multiple servo motors with torque ratings of 15 kg, 40 kg, and 10 kg, operating within safe load limits to ensure stability and precision. The electrical subsystem is controlled by an Arduino-based microcontroller interfaced with H-bridge motor drivers, powered by an 11.1 V rechargeable battery. A DC water pump and solenoid valve regulate water and detergent flow during the cleaning process. The isometric view of the semiautomatic robotic arm was shown in fig.1

The system operates in a semi-automatic mode, where the user initiates the cleaning cycle and the robotic arm follows predefined motion trajectories controlled by programmed logic. The cleaning process involves sequential stages including positioning, pre-spraying of water and detergent, mechanical scrubbing using the rotating brush, and final rinsing. Experimental validation was carried out using both Indian and Western toilets under controlled conditions, with performance compared against manual cleaning methods. Each experiment was repeated five times to ensure consistency, and average values were recorded. Key performance parameters measured include cleaning time, water consumption, detergent usage, cleaning coverage, power consumption, and battery life. Mechanical performance was evaluated based on motor stability, arm accuracy (±3°), maximum load capacity (3.5 kg), and system tilt (limited to 4°), ensuring safe operation. Electrical performance analysis included voltage, current, and power consumption across different operating modes such as idle, movement, brushing, and full operation. Data collected from the experiments were analyzed to assess efficiency improvements and resource optimization. The methodology assumes uniform dirt distribution and controlled environmental conditions, while limitations include the absence of real-time dirt detection and reliance on semi-automatic operation rather than full autonomy.

4. Results and discussions

4.1 Cleaning Performance Analysis

The cleaning performance of the proposed semi-automatic robotic system was evaluated by comparing it with conventional manual cleaning as shown in fig.2 for both Indian and Western toilets. The results indicate a significant reduction in cleaning time. For Indian toilets, the cleaning time decreased from 8.2 minutes (manual) to 4.3 minutes (robotic), resulting in an improvement of approximately 47.5%. Similarly, for Western toilets, the cleaning time was reduced from 7.5 minutes to 3.9 minutes, achieving nearly 48% improvement. This reduction is primarily due to the optimized and continuous motion of the robotic arm, which eliminates delays associated with manual operations and enables simultaneous execution of cleaning tasks such as spraying and scrubbing.

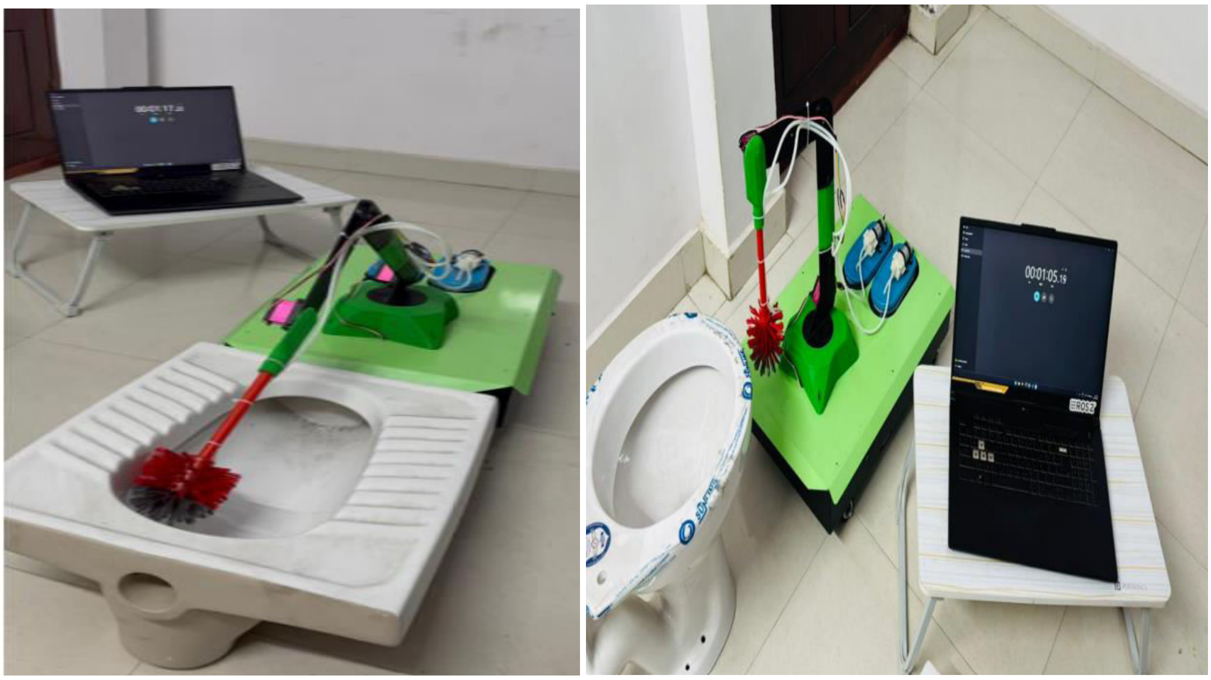
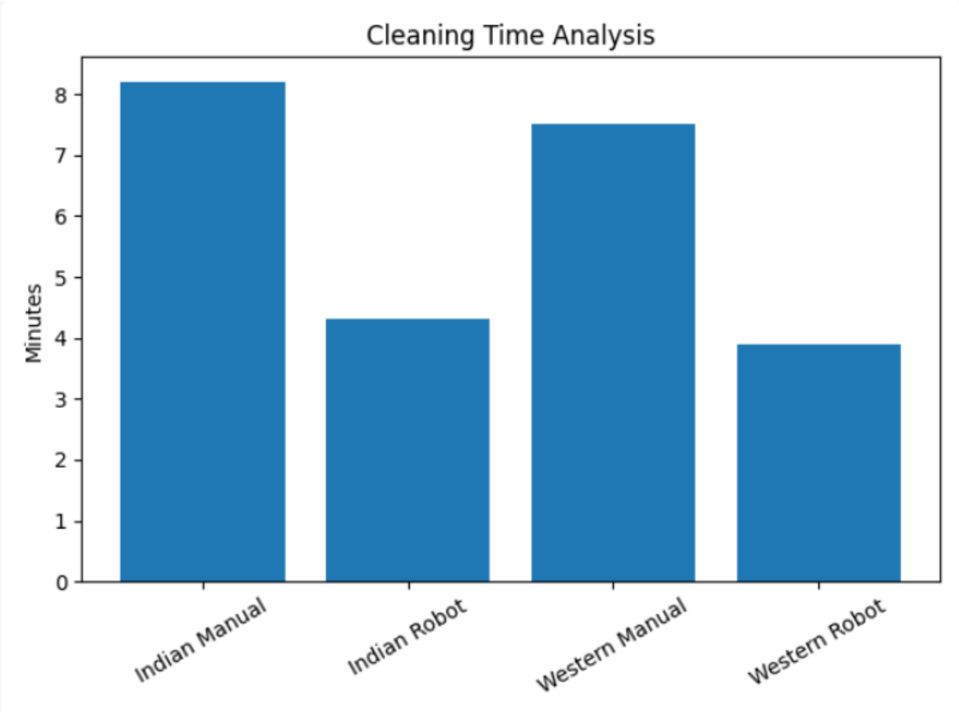
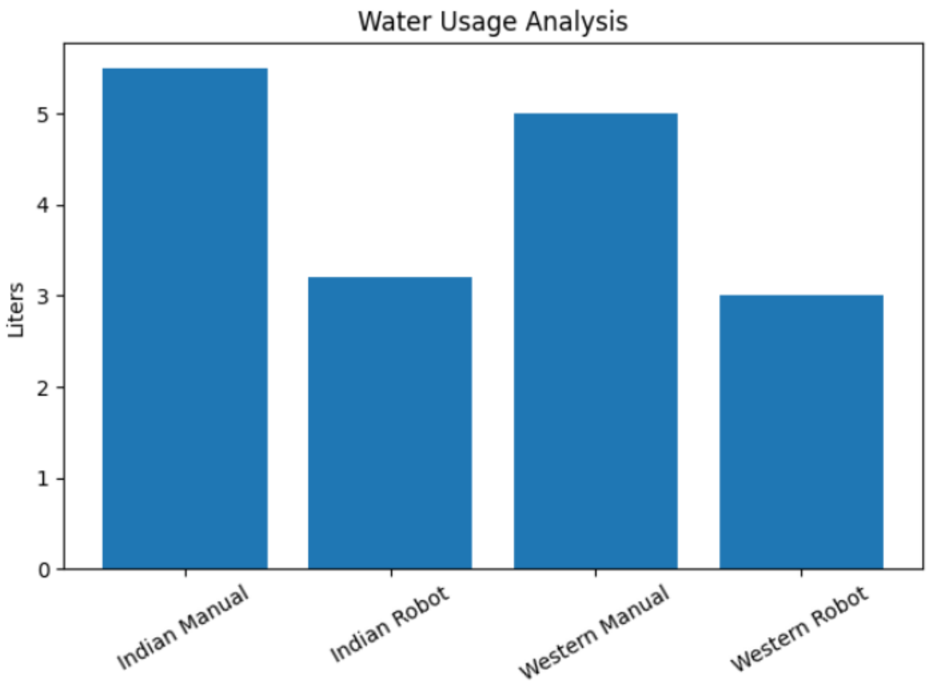


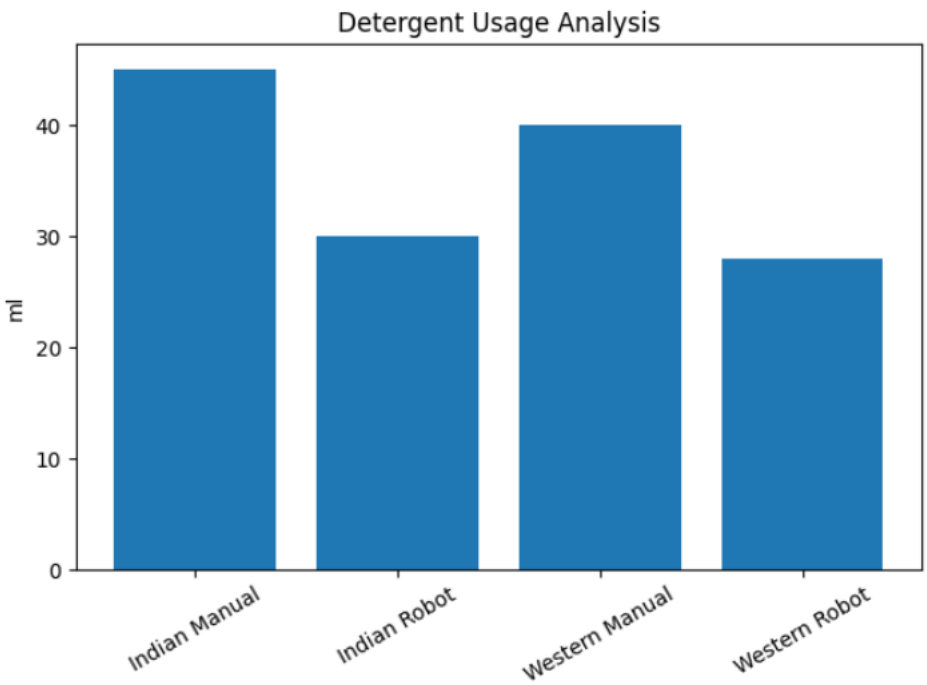
Fig.2 Cleasning Performance analyis of indian toilet i)indian toilet ii) Western toilet



4.2 Water Usage Analysis

The proposed system demonstrates efficient utilization of cleaning resources, particularly water and detergent. Experimental results show that water consumption was reduced from 5.5 liters in manual cleaning to 3.2 liters using the robotic system, corresponding to a reduction of approximately 41%. Similarly, detergent usage decreased from 45 ml to 30 ml, resulting in a 33% reduction. This improvement is attributed to controlled spraying mechanisms and precise application of cleaning agents, which minimize wastage while maintaining effective cleaning performance. The reduction in resource consumption highlights the system's potential for environmentally sustainable sanitation.

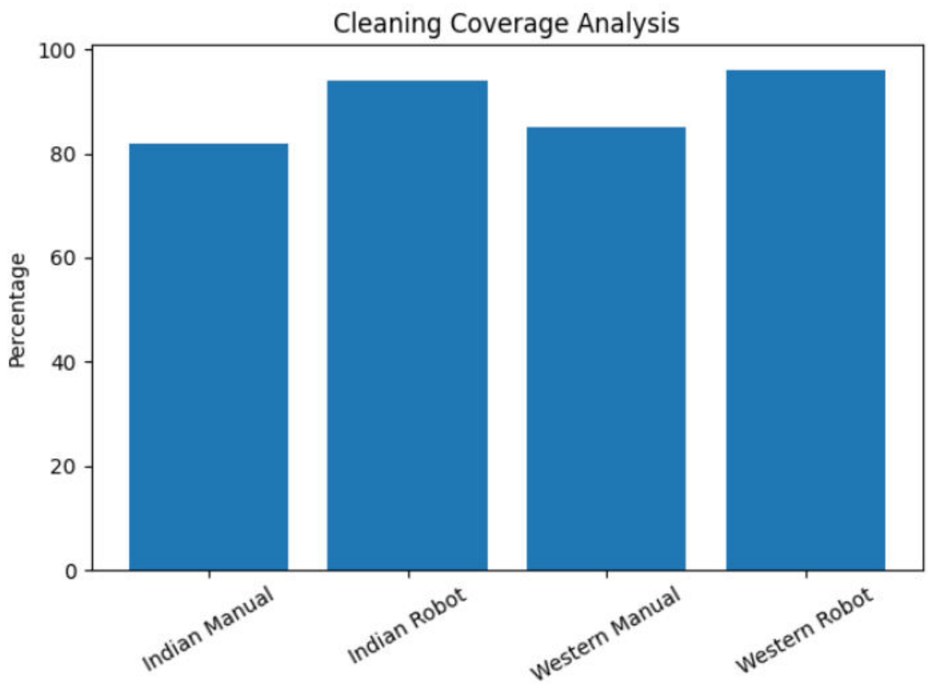




4.3 Cleaning Coverage Efficiency

Cleaning coverage efficiency was estimated to evaluate the effectiveness of the proposed robotic system in cleaning the entire toilet surface. In this study, a grid-based visual inspection method was adopted, wherein the toilet surface (both Indian and Western types) was conceptually divided into multiple uniform sections covering critical regions such as the inner bowl, rim, corners, and base areas. A uniform layer of test dirt was initially applied to the surface to simulate real cleaning conditions. After performing the cleaning operation using both manual and robotic methods, each grid section was visually inspected and classified as either cleaned (no visible stains or residues) or not cleaned (presence of visible dirt). The cleaning coverage efficiency was then calculated as the ratio of the number of cleaned sections to the total number of sections, expressed as a percentage. The results indicated that the robotic system achieved higher coverage values (94–96%) compared to manual cleaning (82–85%), primarily due to its controlled and repeatable motion, consistent brush contact, and uniform distribution of water and detergent. Although the method provides a practical estimation of cleaning performance, it is limited by its reliance on visual inspection and does not account for microscopic contaminants. Future improvements may include the use of image processing or sensor-based techniques to obtain more accurate and objective measurements of cleaning efficiency.

The robotic system achieved significantly higher cleaning coverage compared to manual methods. For Indian toilets, coverage improved from 82% to 94%, while for Western toilets, it increased from 85% to 96%. This enhancement is mainly due to the repeatability and precision of the robotic arm, which ensures consistent contact with the cleaning surface and effective reach into difficult areas. The ability of the robotic arm to follow predefined trajectories contributes to uniform cleaning and improved overall hygiene.



4.4 Mechanical Performance Evaluation

Mechanical performance analysis confirms that the system operates within safe and stable limits. The base motor, rated at 200 RPM, operated at approximately 185 RPM under load, indicating stable performance. The servo motors functioned within their rated torque capacities, with no signs of overloading during operation. The arm accuracy was measured to be within ±3°, which is acceptable for cleaning applications. Additionally, the maximum load capacity of 3.5 kg ensured safe handling of the cleaning components. The system exhibited good structural stability, with a tilt angle limited to 4°, preventing any risk of tipping during operation.

4.5 Electrical Performance Analysis

The electrical performance of the system was evaluated under different operating modes. The power consumption ranged from 4.4 W in idle mode to 35.5 W during full operation. The current consumption varied from 0.4 A to 3.2 A at a constant voltage of 11.1 V. The battery provided a backup duration of approximately 42 minutes under full load conditions, which is sufficient to perform multiple cleaning cycles. These results indicate that the system is energy-efficient and suitable for practical deployment in real-world sanitation environments.

The overall performance of the proposed robotic system demonstrates significant advantages over manual cleaning methods. The system achieves reduced cleaning time, lower resource consumption, and improved cleaning coverage while ensuring stable mechanical and electrical operation. Furthermore, the reduction in human contact with contaminated surfaces enhances safety and hygiene. However, the system currently operates based on predefined motion paths and lacks real-time dirt detection capabilities, which could further improve efficiency. Future enhancements may include the integration of intelligent sensors and adaptive control algorithms to enable fully autonomous operation.

Conclusions and future scope

The present study successfully developed and experimentally validated a semi-automatic three-axis robotic arm for cleaning both Indian and Western toilets. The results demonstrate that the proposed system significantly enhances cleaning efficiency by reducing cleaning time by nearly 48%, water consumption by 41%, and detergent usage by 33%, while achieving a high cleaning coverage of up to 96%. The integration of a 3-DOF robotic manipulator with a coordinated spraying and scrubbing mechanism ensures effective cleaning of complex surfaces and hard-to-reach areas. Mechanical and electrical evaluations confirm that the system operates reliably within safe limits, with stable motor performance, acceptable positional accuracy, and efficient power consumption. The system also minimizes human exposure to hazardous environments, thereby improving safety and hygiene standards in sanitation applications. Overall, the proposed system provides a cost-effective, practical, and scalable solution for modern cleaning requirements in public and private facilities.

References

1. B. Xiong, Y. Zhang, and H. Li, “Vision-based sewer inspection and cleaning robot,” *Applied Sciences*, vol. 15, no. 7, pp. 1–18, 2025.
2. A. Abd Eltwab, M. Hassan, and K. Ibrahim, “Design of a multi-purpose service robot with robotic arm,” *Journal of Intelligent Service Robotics*, vol. 18, pp. 245–260, 2025.
3. J. Lee and K. Park, “Multi-DOF robotic manipulators for industrial cleaning applications,” *IEEE Access*, vol. 10, pp. 112345–112356, 2022.
4. S. Kumar and R. Patel, “Kinematic modeling of robotic arms for automation,” *Mechanism and Machine Theory*, vol. 182, 2023.
5. Y. Chen and S. Pan, “Design of intelligent cleaning robot using embedded systems,” *Mechanical Engineering Advances*, vol. 4, no. 2, pp. 55–67, 2025.
6. M. Rahman et al., “Smart cleaning robots with IoT integration,” *IEEE Internet of Things Journal*, vol. 11, no. 3, pp. 4567–4578, 2024.
7. T. Nguyen and D. Tran, “Vision-guided robotic cleaning systems,” *Robotics and Autonomous Systems*, vol. 165, 2023.
8. P. Sharma and A. Singh, “Design of 3-DOF robotic arm for service applications,” *International Journal of Robotics Research*, vol. 42, no. 5, pp. 789–802, 2023.
9. K. Kim et al., “Autonomous UV-C disinfection robot for hospitals,” *IEEE Robotics and Automation Letters*, vol. 10, no. 1, pp. 112–119, 2025.
10. L. Wang and X. Zhao, “AI-based robotic cleaning systems for smart environments,” *Expert Systems with Applications*, vol. 235, 2024.
11. S. Li et al., “Reconfigurable modular cleaning robot for complex surfaces,” *Expert Systems with Applications*, vol. 230, 2024.
12. R. Gupta and V. Mehta, “Water-efficient robotic cleaning technologies,” *Journal of Cleaner Production*, vol. 389, 2023.

13. N. Reddy and P. Kumar, “Sanitation challenges in developing countries,” *Environmental Engineering Research*, vol. 27, no. 4, 2022.
14. A. Jain and S. Verma, “Semi-automatic robotic systems for cleaning applications,” *Automation in Construction*, vol. 148, 2023.
15. M. Das et al., “Cost-effective service robots for public sanitation,” *Sustainable Cities and Society*, vol. 96, 2024.