Review of Wall Climbing Cleaner Robot

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***Abstract*—The cleaning and maintenance of high-rise buildings and vertical structures pose serious safety risks and high operational costs when performed manually. To address these challenges, this paper reviews recent developments in wall- climbing and cleaning robotic systems with emphasis on adhesion mechanisms, mobility, control strategies, and energy management. Various techniques such as vacuum suction, propeller- based thrust, bio-inspired adhesion, and hybrid aerial–climbing systems are analyzed. The study highlights the advantages of autonomous and semi-autonomous robots in improving safety, efficiency, and cleaning consistency while reducing human intervention. Challenges related to adhesion reliability, power consumption, and limited autonomy are also discussed. Based on the review, the paper identifies research gaps and outlines future directions toward developing intelligent, energy-efficient, and fully autonomous wall-climbing cleaner robots for modern infrastructure maintenance.**

***Index Terms*—Wall climbing robot, suction adhesion, Arduino, BLDC motor, automation, fac¸ ade cleaning, robotics.**

I. INTRODUCTION

The growing number of skyscrapers and glass fac¸ ades in urban environments has increased the need for efficient and safe cleaning systems. Traditional manual cleaning methods expose workers to significant risks and require high operational costs. Robotics offers a viable alternative by enabling automation in fac¸ade cleaning, reducing human intervention, and increasing precision.

Recent advancements in embedded systems, sensor technologies, and lightweight actuators have made it feasible to design compact robots capable of climbing and cleaning vertical surfaces. However, challenges remain in ensuring stable adhesion, efficient cleaning, energy optimization, and obstacle detection. The Wall Climbing Cleaner Robot developed in this project aims to address these challenges through a hybrid system combining suction-based adhesion and wheeled traction, integrated with a real-time control system.

II. LITERATURE REVIEW

A. Propeller-Type Wall-Climbing Robot for Visual and Ham- mering Inspection of Concrete Surfaces (Yuki Nishimura et al., 2024)

This paper presents the design and implementation of a propeller-based wall-climbing robot intended for inspection of large concrete structures. The robot uses thrust generated by multiple propellers to adhere securely to vertical and inclined surfaces. A visual inspection system using high-resolution cameras enables real-time surface monitoring. Additionally, a hammering inspection mechanism is integrated to detect inter- nal defects through acoustic signal analysis. The combination of visual and hammering inspection improves defect detection accuracy. The thrust-based adhesion system provides strong and adjustable attachment force. Experimental results show stable climbing and inspection performance on concrete walls. The system significantly reduces risks associated with human inspection at heights. The robot demonstrates high potential for infrastructure maintenance applications. Overall, the study validates thrust adhesion as a reliable wall-climbing solution.

B. Design and Development of Wall Climbing Robot for Crack Detection (Shubham Pawar et al., 2023)

This research focuses on the development of a wall-climbing robot specifically for detecting surface cracks in building structures. The robot employs a ducted fan mechanism to generate suction force for wall adhesion. A high-resolution camera is mounted to capture detailed images of wall surfaces. Image processing techniques are used to identify and analyze cracks in real time. The system eliminates the need for scaffolding and manual inspection. The robot improves inspection efficiency while enhancing worker safety. Lightweight materials are used to reduce power consumption. Experimental tests confirm reliable adhesion and crack detection accuracy. The robot can operate on vertical concrete and painted walls. The study highlights the feasibility of automated crack inspection systems.

C. Wall Climbing Robot Using Vacuum Suction Mechanism (Dr. P. Srinivasan et al., 2022)

This paper proposes a wall-climbing robot that utilizes a vacuum suction mechanism for adhesion. The robot is de- signed to perform multiple tasks such as inspection, cleaning, and painting. Vacuum chambers generate sufficient negative pressure to support the robot's weight. A modular architecture allows easy attachment of different operational tools. The system is capable of climbing smooth vertical surfaces effectively. Stability and load-carrying capacity are experimentally evaluated. The robot demonstrates reliable movement and task execution on walls. The vacuum-based approach provides strong adhesion with minimal slippage. Power consumption is optimized through efficient suction control. The study concludes that vacuum adhesion is suitable for industrial wall- climbing applications.

D. Lizard-Inspired Wall-Climbing Robot Using Pressure- Sensitive Adhesion (Satyendra R. Nishad et al., 2022)

This research introduces a bio-inspired wall-climbing robot modeled after lizard locomotion. The robot uses pressure- sensitive adhesive pads to achieve wall attachment. These pads generate adhesion through contact forces rather than suction or magnets. The design ensures continuous surface contact, improving stability during climbing. The robot consumes less energy compared to vacuum-based systems. Locomotion is achieved using synchronized limb movements. The system can adapt to uneven and slightly rough surfaces. Experimental results demonstrate reliable climbing on vertical walls. The bio-inspired approach reduces mechanical complexity. The study emphasizes the advantages of nature-inspired adhesion mechanisms in robotics.

E. Wall-Climbing Robot for Cleaning Silo Using Vacuum Principle (Van-Tinh Nguyen et al., 2021)

This paper presents a wall-climbing robot designed for cleaning industrial silos using vacuum adhesion. The robot is capable of operating on curved and uneven silo surfaces. A Z- shift movement mechanism enhances stability during vertical motion. The vacuum system provides consistent adhesion under varying surface conditions. Cleaning tools are integrated for efficient residue removal. The robot reduces the need for human entry into hazardous environments. Experimental evaluations confirm stable climbing and cleaning performance. The system improves workplace safety and operational efficiency. The robot is suitable for large-scale industrial cleaning tasks. The study validates vacuum-based climbing for confined industrial structures.

F. Wall-Climbing Drone with Vertical Soft Landing Using Tilt- Rotor Mechanism (Wancheol Myeong and Hyun Myung, 2018)

This research introduces a hybrid wall-climbing drone capable of both aerial flight and wall adhesion. A tilt-rotor mechanism enables smooth transition from flight to wall contact. The soft landing strategy minimizes impact forces during attachment. The drone can access locations unreachable by traditional climbing robots. Once attached, the system maintains stable adhesion for inspection tasks. The hybrid design increases operational flexibility. Control algorithms manage rotor orientation and thrust distribution. Experimental results demonstrate safe and reliable wall attachment. The system is suitable for inspection of tall and complex structures. The study highlights the advantages of combining aerial and climbing robotics.

G. Autonomous Self-Reconfigurable Floor Cleaning Robot (Rizuwana Parween et al., 2020)

This paper discusses the design of an autonomous floor- cleaning robot with self-reconfigurable capabilities. The robot consists of multiple interconnected modules. It can change its shape to adapt to different floor layouts. Reconfiguration improves area coverage and navigation efficiency. The system autonomously adjusts its configuration based on environmental conditions. Coordinated control algorithms manage module movement. Experimental results show improved cleaning performance compared to fixed-shape robots. The robot handles obstacles effectively. Energy efficiency is enhanced through optimized motion planning. The study demonstrates the bene- fits of reconfigurable robotic systems for cleaning applications.

H. Scalable Coverage Path Planning for Cleaning Robots Using Rectangular Map Decomposition (Xu Miao et al., 2018)

This paper proposes a scalable coverage path-planning algorithm for autonomous cleaning robots. The environment is divided into rectangular regions using map decomposition. This approach reduces computational complexity. The robot systematically covers each region to ensure complete area coverage. The method improves cleaning efficiency in large environments. Path overlap and redundancy are minimized. The algorithm is suitable for real-time implementation. Simulation results show improved performance over conventional methods. The approach supports scalability for large indoor spaces. The study contributes to efficient navigation strategies for cleaning robots.

I. Design and Development of Floor Cleaner Robot (Minal Amrutkar et al., 2021)

This research presents a low-cost floor-cleaning robot de- signed using simple hardware components. The robot is con- trolled via Bluetooth communication. It operates in both manual and semi-autonomous modes. A microcontroller manages motor control and cleaning mechanisms. The design focuses on affordability and ease of use. The robot effectively removes dust and debris from flat surfaces. Power consumption is kept minimal. Experimental testing confirms reliable operation. The system is suitable for household cleaning applications. The study demonstrates a practical approach to low-cost automation.

J. Reconfigurable Floor Cleaning Robot with Infinite Mor- phologies – hTetro-Infi (S.M. Bhagya P. Samarakoon et al., 2020)

This paper introduces a reconfigurable floor-cleaning robot composed of tetromino-shaped modules. The robot can form infinite configurations to adapt to different environments. Shape transformation helps navigate narrow spaces and obstacles. The system dynamically selects optimal morphologies during operation. Coordinated control enables smooth reconfiguration. Experimental results show enhanced cleaning efficiency. The robot reduces uncleaned areas near obstacles. Energy usage is optimized through adaptive configurations. The modular design improves flexibility. The study highlights the potential of infinite-morphology robots in cleaning tasks.

K. Energy and Coverage Trade-off in Self-Reconfigurable Cleaning Robots (M.A. Viraj J. Muthugala et al., 2020)

This research analyzes the relationship between energy consumption and area coverage in reconfigurable cleaning robots. A fuzzy logic-based decision-making system is proposed. The robot dynamically adjusts its configuration based on energy and coverage requirements. User preferences influence cleaning strategies. The system balances performance and battery life. Simulation results demonstrate improved efficiency. The approach reduces unnecessary energy consumption. The robot adapts to different cleaning priorities. The study provides insights into intelligent energy management. The findings are useful for autonomous service robots.

L. Prediction of Remaining Useful Life of Lithium-Ion Batteries Using Deep Learning (Jianshu Qiao et al., 2020)

This paper proposes a deep learning-based approach for predicting the remaining useful life of lithium-ion batteries. A hybrid neural network model is developed for accurate prediction. The model analyzes voltage, current, and temperature data. Accurate battery life prediction improves system reliability. The approach reduces unexpected battery failures. Although not specific to wall-climbing robots, it is highly relevant. Autonomous robots rely heavily on battery performance. The method enhances power management strategies. Experimental results show high prediction accuracy. The study supports the integration of AI-based battery monitoring in robotics.

III. METHODOLOGY

The research methodology followed in the development of the wall-climbing cleaner robot consists of five major phases: requirement analysis, mechanical–electrical design, adhesion and propulsion calibration, control system programming, and experimental evaluation.

A. Requirement Analysis and Design Specification

The first stage involved defining performance metrics necessary for effective facade cleaning. These included:

- Minimum adhesion force grater than robot weight + friction reserve

Stage	Operation
Initialization-	System boots, Bluetooth paired
Adhesion Ramp-Up-	Propeller speed gradually increases to target RPM
Climbing Mode-	Wheels activated only after stable suction achieved
Cleaning Mode-	Brush engaged; servo adjusts pressure angle
Emergency Override-	Manual stop command possible at any stage

- Climbing speed greater than 5 cm/s for practical cleaning time
- Cleaning efficiency greater than 90% for dust removal
- Maximum robot mass less than 2 kg to ensure low thrust requirement
- Battery runtime greater than 20 minutes

B. Control System Architecture

An Arduino Nano microcontroller governs all subsystem operations. The electronic circuitry consists of:

- L298N driver – controlling bidirectional wheel motion
- A2212 BLDC motor with 30A ESC – driving the cleaning brush
- MG90S servo motors – adjusting brush angle contact
- HC-05 Bluetooth module – joystick command reception
- Wi-Fi camera module – remote video streaming

The software follows a hierarchical finite-state machine (FSM):

PWM control ensured gradual thrust buildup, preventing sudden detachment or shock load.

C. Adhesion Calibration and Parameter Tuning

Prior to field testing, laboratory thrust calibration was con- ducted. Using a digital scale, downward force was measured for various BLDC throttle levels. Adhesion RPM-vs-force curve was plotted to select the minimum safe RPM. Surface friction tests determined the optimal cleaning angle, preventing brush stalling.

Battery discharge tests at partial load identified an average runtime of 23 minutes, matching design expectations.

IV. CONCLUSION

This literature review examined various wall-climbing and cleaning robotic systems utilizing adhesion mechanisms such as vacuum suction, propeller-based thrust, bio-inspired pads, and hybrid aerial approaches. The reviewed studies demonstrate significant improvements in safety, efficiency, and ac- curacy for inspection and cleaning tasks on vertical and hazardous surfaces. Modular and self-reconfigurable robot designs enhance adaptability and coverage in complex environments. Advanced path-planning and energy management strategies further improve autonomous operation and efficiency. How- ever, challenges related to energy optimization, adhesion reliability, and full autonomy remain, motivating further research in intelligent wall-climbing robotic systems.

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