Multi-Tasking Wall Robot

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Abstract**—** The Wall Climbing Robot designed in this study combines the innovative propulsion system of propellers with the traditional locomotion method of wheels to achieve versatile and efficient mobility on both vertical and horizontal surfaces. By integrating propellers and wheels, the robot can seamlessly transition between climbing walls and moving along flat surfaces. The presented is able to enhance robots mobility and optimize its efficiency which ultimately makes it suitable for prolonged missions in various environments. This research explores the synergistic integration of propellers and wheels, showcasing the robot's adaptability in real-world applications such as surveillance, inspection, and maintenance tasks in both indoor and outdoor scenarios. The developed Wall Climbing Robot presents a significant advancement in robotic mobility, offering a promising solution for complex tasks in diverse settings.

Keywords**— *Propellers, Wheels, Hybrid Locomotion, Robotics, Mobility, Sensors, Vertical Surface Traversal, Horizontal Movement,***

INTRODUCTION

The field of robotics continues to push boundaries, embracing new challenges and technologies to develop versatile and adaptable machines capable of overcoming various obstacles. Wall climbing robots, in particular, have garnered significant attention due to their potential applications in inspection, maintenance, and surveillance tasks within complex environments. This study introduces a novel approach to designing a Wall Climbing Robot, leveraging a simplistic wheeled chassis and an innovative propeller-based thrust mechanism to enable the robot to ascend vertical surfaces.

Traditional wall climbing robots have often relied on complex mechanisms and intricate designs, which can impede their mobility and increase their energy consumption. In contrast, the proposed approach aims to simplify the robot's structure while maintaining its effectiveness in climbing walls. The integration of a wheeled chassis provides stability and enhances manoeuvrability, allowing the robot to traverse diverse terrains effectively. The introduction of a propeller-based thrust mechanism offers an efficient solution for generating the necessary force to facilitate climbing.

The primary objective of this research is to investigate the feasibility of utilizing a straightforward wheeled chassis and propeller thrust to create a capable wall climbing robot. By focusing on simplicity without compromising functionality, this study aims to address existing challenges in wall climbing robotics, such as complex mechanisms, power consumption, and stability. The robot's ability to navigate vertical surfaces using a simplified design holds the potential to revolutionize various industries, from construction and infrastructure maintenance to search and rescue operations.

Throughout this study, we will developed into the design process, the integration of the propeller thrust mechanism, and the experimental validation of the robot's climbing capabilities. By showcasing the advantages of this approach, we hope to contribute to the advancement of wall climbing robotics and inspire new directions in robot design and application.

LITERATURE SURVEY

The paper discusses the design and fabrication of a quadruped climbing robot capable of ascending vertical surfaces. The robot utilizes a suction mechanism for wall adhesion and is controlled using Basic Stamp, with leg movement generated by dual servo motors. These motors independently control legs on both sides of the robot, employing slider and crank mechanisms to simulate stepping motions. Suction force is intermittently activated by vacuum pumps, and the robot's compact body integrates all components except the compressor. While currently limited to linear movement, future plans involve enhancing manoeuvrability and functionalities based on successful initial implementation [1].Climbing robots are being developed to address a wide spectrum of applications, spanning from cleaning to inspecting challenging structures. These robots need to possess the capacity to navigate vertical surfaces while carrying a light payload and overcoming obstacles. In terms of surface adhesion, they should exhibit versatility across various surfaces, utilizing adhesion methods that generate strong grip with minimal power consumption. Within this context, this paper introduces a 4-legged Wall Climbing Robot, utilizing on board suction pumps for adhesion. A walking gait has been devised to enable the robot to scale walls, with its kinematics and motion resembling techniques used in rock climbing. Featuring four legs, each boasting four degrees of freedom (4-DOF), the robot employs specially designed suction cups at the end of each leg for wall traversal and omnidirectional movement. The robot's end effector can also be swapped with others designed for diverse adhesion methods to navigate an array of surfaces [2].This paper introduces a novel concept of a wall-climbing robot with the ability to ascend vertical surfaces. The robot achieves continuous locomotion at a notable climbing speed of 15m/min through the utilization of a series chain mechanism integrated with two tracked wheels. These wheels host 24 suction pads that adhere to the vertical plane. Sequential activation of the suction pads is orchestrated by specially designed mechanical valves, synchronized with the rotation of each tracked wheel. The comprehensive engineering analysis encompasses the intricate design of the tracked wheel, mechanical valves, and overarching features. This self-contained robot incorporates an integrated vacuum pump and power supply, controlled remotely. The climbing performance, enabled by the proposed mechanism, is assessed on a vertical steel plate. Additionally, the paper outlines the steps for an optimization experiment using the Taguchi methodology to enhance vacuum pressure, a pivotal factor in augmenting suction force[3]. The paper unveils a wall-climbing robot tailored for high-rise building inspection and glass cleaning applications. It introduces an innovative quadruped mechanism, seamlessly integrating a four-bar and slider crank mechanism with a vacuum adhesion module. An adhesion feedback system bolstered by intelligent gripping guarantees steadfast attachment between the vacuum cup and the graspable surface. The climbing motion is meticulously examined, culminating in the development of a prototype wall-climbing robot characterized by its compact size and minimal power consumption. Rigorous performance tests are carried out, showcasing the robot's exceptional stability, commendable weight-bearing capacity, and the absence of convoluted control logic [4]. This paper introduces a wall climbing robot that employs a semi-static movement approach. The climbing robot is designed as a wheeled robot for vertical surfaces, addressing the planning challenge which is among the key obstacles in developing a practical mechanical system capable of scaling natural terrain. Both hardware design and control aspects are thoroughly explored. The robot is designed to achieve wall adhesion effectively and efficiently, utilizing lightweight materials. The design is iteratively tested in various locations, determining the optimal propeller speed for wall adherence. The vertical and downward movement of the robot is subsequently experimented with and executed using motors and propellers [5]Following study is dedicated to the development of a wall climbing robot with a focus on non-destructive inspections of various building structures, such as bridges, concrete buildings, tunnels, and dams, to detect surface cracks. The robot utilizes a general-purpose vacuum suction mechanism for adhesion, enabling it to climb both horizontal and vertical surfaces. The analysis of captured images is conducted using image processing techniques, employing a camera integrated with a Raspberry Pi for control and image capture. The images are sent in a series to a computer for processing, where algorithms including image pre-processing, segmentation, grayscale conversion, thresholding, and edge detection are applied. Different edge detection operators such as Canny, Sobel, Roberts, Prewitt, and LoG are employed to detect surface cracks. Parameters like crack area are estimated through image processing, providing outputs in pixel values that are subsequently converted into corresponding dimensions [6].The given project primarily addresses performance evaluation challenges in industrial applications, particularly within the piping sector. The core focus is the integration of robotics and magnetic technologies, utilizing permanent magnetic tracks, to enhance the inspection and cleaning of pressure vessels. The project involves experimental assessment, where a wall climbing robot is integrated with a permanent magnetic adhesion mechanism to inspect pipes and duct systems. The proposed system's conceptual design, accounting for various operational parameters, is created using a suitable CAD modeler (CATIA). The hardware includes multiple sensors and an Arduino controller to ensure seamless automation. The study also involves exploring Arduino programming for the experimental evaluation of the robotic system's functionality [7]. Climbing robots have found extensive utility in inspecting smooth walls; however, devising an effective adhesion method for inspecting cliff surfaces and dusty, high-altitude terrains with minimal vibration, which are predominantly composed of coarse concrete, square brick, or rock, remains a challenge. In this study, we commence by analyzing the bionic structure of cockroach legs, closely observing their morphological attributes, including spiny claws. Additionally, we delve into the interaction theory of these bionic claws with protuberances on rugged wall surfaces and deduce the mechanical prerequisites for secure claw engagement with these protuberances. Subsequently, an initial mechanical framework for a wall-climbing robot is introduced, grounded in a grasping claw and climbing model. Furthermore, a mathematical model is formulated to elucidate the relationship between sharp hooks and the bulges on uneven walls. Concluding the study, a series of laboratory experiments are conducted to authenticate the grasping stability of the proposed design [8].The realm of industrial inspection tasks holds tremendous potential for climbing robots, especially those equipped to function in hazardous environments, scale diverse surfaces, and navigate tight and challenging spaces. Their applications span a wide spectrum, including cleaning, painting, repairing, diagnostic inspection of building walls, non-destructive testing inspection, and maintenance of facilities like oil storage tanks, nuclear power plants, petrochemical factories, and medical contexts. This paper elaborates on various robot adhesion techniques applicable in different environments, some of which have been integrated into wall-climbing robot designs. The discussed adhesion methods encompass a range of approaches, such as permanent magnets, vacuum suction cups, propellers, needles or grippers, glue or adhesive tape, and the Van der Waals effect [9].The primary challenge in the domain of wall-climbing robots lies in their ability to maintain grip on the wall, encompassing various influencing factors such as forces, robot movement, and mechanical design. In response, this study introduces a movement step design for a wall-climbing robot, employing a pneumatic system as its core mechanism for wall traversal. The robot is enabled to maneuver in four directions: forward, backward, left, and right. Through a comprehensive analysis of the forces at play against the wall, it is determined that the wall's slope should ideally range from 0° (parallel to the ground) to 90° (vertical line). Equilibrium conditions are expressed through the summation of all forces equating to zero. The study suggests two strategies for enhancing climbing efficiency: altering wall material to increase the coefficient of friction (μs) or enhancing the vacuum force through improved pneumatic system efficiency [10].This paper introduces a wall-climbing robot that employs passive suction cups as its attachment components, enabling both wall traversal and attachment-detachment maneuvers with a single motor. The use of passive suction cups eliminates the need for additional energy consumption to maintain adhesion, resulting in relatively low energy consumption during climbing. The prototype has been designed, fabricated, and tested, revealing the robot's ability to passively attach and detach suction cups. However, challenges were encountered in the robot's ability to ascend the wall, leading to frequent falls. To address this, the paper analyzes the load distribution of attached suction cups on a vertical wall and identifies a moment generated by gravity and the attaching force as the cause of downward movement. As a solution, a new model is proposed to mitigate these falling issues [11]. Robug IIs is a versatile legged climbing robot specifically engineered to navigate through unstructured and challenging terrains. Unlike wheeled-tracked vehicles that are best suited for flat surfaces, Robug IIs exhibit the capability to walk, climb vertical surfaces, and autonomously transfer from the floor to walls. Its sensing approach relies on tactile and ultrasonic sensing, enabling it to adapt to uncertain environments. The robot's intelligence is further enhanced through a set of reflexive rules, enabling it to respond effectively to environmental uncertainties. Additionally, Robug IIs can independently locate and verify secure footholds, enhancing its navigational prowess [12].Conventional wall-climbing robots predominantly rely on rigid actuators, such as electric motors, leaving a gap for the realization of soft wall-climbing robots driven by muscle-like actuators. This study presents a tethered soft robot that achieves vertical wall climbing on wood, paper, and glass surfaces at a speed of up to 0.75 times its body length per second, demonstrating versatile multimodal locomotion including climbing, crawling, and turning. This soft wall-climbing robot leverages dielectric-elastomer artificial muscles that induce rapid periodic deformation of its flexible body, electroadhesive feet providing controlled adhesion, and a synchronized control strategy harmonizing body deformation and feet adhesion for stable climbing. Additionally, the robot showcases its capability to carry a camera for vertical tunnel videos, adjust its body height for confined spaces, and navigate complex planar trajectories. This achievement mimics the agile adaptability observed in soft organisms with vertical climbing proficiency [13]. Concrete structures, such as bridges or viaducts, hold significant importance in global road infrastructure, though they are susceptible to external factors that lead to structural deterioration over time. Regular inspection becomes crucial to mitigate this impact, often necessitating risky and costly manual assessments using specialized equipment. To address these challenges, the research project ASAP (Autonomous System for Assessment and Prediction of Infrastructure Integrity) has developed a prototype wall-climbing robot (WCR) for nondestructive testing (NDT). This paper presents various iterations of the WCR prototypes, showcasing advancements in adhesion and locomotion systems across four designs. The fifth prototype, equipped with NDT equipment, is highlighted. The final WCR version boasts robust and flexible adhesion mechanisms suitable for diverse surfaces, while integrating NDT equipment poses additional challenges, which are discussed. Beyond the WCR, the paper also delves into the essential components of a successful inspection, including safety systems, control, and power mechanisms [14]. The study describes the design and development of a climbing robot capable of performing visual and Ground Penetrating Radar (GPR) inspections. Yang, Liang, Guoyong Yang, Zhaoming Liu, Yong Chang, Biao Jiang, Youssef Awad, and Jizhong Xiao are among the paper's authors. The goal of the robot is to do inspections in industrial environments where climbing walls is essential for efficient examination. The report will most likely include details about the robot's design, capabilities, wall climbing methods, visual inspection, GPR technology integration, and possibly some experimental fi dings or case studies. The robot's mission is to improve [15].The description of magnetic wall-climbing robots used for inspection. It discusses their design, mechanisms, applications, and difficulties. Based on design variants, movement strategies, sensors, and application domains, the article categorizes and assesses existing robots. It emphasizes benefits such as increased efficiency and lower risk while emphasizing concerns like stability and control. Overall, the study serves as a complete reference to magnetic wall-climbing robots, highlighting their accomplishments and possible applications in a variety of inspection jobs[16].The study is on a small flying robot designed to climb walls. The paper discusses the mechanism's design and operation, emphasizing its aerial capabilities and climbing functionality. The MAV's potential applications and its integration into wall-climbing tasks are explored. The paper was presented at the 2013 IEEE RO-MAN conference and provides insights into the innovative mechanism for combining aerial mobility with wall-climbing ability in a robotic system [17]. They describe a wall-climbing robot for metric concrete inspection in this study. It can access inaccessible places and provide a close-up view for visual data collecting and real-time flaw detection and localisation. The wall-climbing robot can identify surface problems in concrete (such as cracks and spalls) and create a 3D representation of the defect that is highlighted and includes extracted location information and metric measurements[18].The article explained a wall-climbing robot for metric concrete inspection is described in this study. 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Published in the Journal of Intelligent & Robotic Systems, the study delves into the details of creating a specialized gripper mechanism tailored for the climbing robot's specific requirements. The paper elaborates on the design considerations, development process, and realization of the claw gripper system. By addressing both the conceptual framework and the practical aspects of the system, the authors contribute to the advancement of climbing robot technology. The work provides valuable insights into enhancing the gripping capabilities of climbing robots, which could have implications for various applications involving challenging terrains and vertical surfaces [20]. The article explained about multidirectional magnetized permanent magnetic adsorption device's design ideas, fabrication techniques, and functionalities were covered in detail in the study. The authors develop climbing robot technology by tackling the difficulties of robot mobility on walls. The discovery offers important insights into enhancing robot wall-climbing abilities, which may find use in a variety of fields needing precise and flexible adhesion methods [21]. This study introduces the Vortexbot, a wall-climbing robot with a suction device that creates a suction force via vortex movement. The suction unit does not touch the wall surface, in contrast to the conventional unit based on contact-type adsorption, which significantly minimizes frictional resistance between the robot and wall and enhances the robot's passing ability. It begins by explaining the vortex suction unit's basic operation. The mechanical design of Vortexbot is next developed by the authors. On a smooth wall surface, they also examine the suction characteristics of the suction device. They also investigate the surface roughness and shape [22].

METHODOLOGY

The development of the Wall Climbing Robot involves a systematic approach encompassing several key steps. Firstly, a lightweight and sturdy wheeled chassis is designed, integrating DC motors to enable locomotion. A propeller-based thrust mechanism is strategically positioned and optimized through iterative testing to facilitate efficient wall climbing while minimizing energy consumption. An LM35 motor driver ensures smooth movement, while control electronics and a user-friendly app are employed for remote control via Wi-Fi connectivity. A wireless communication setup is established, enabling real-time command transmission and feedback between the robot and the controlling device. Algorithms are developed to convert user input into precise control signals, ensuring accurate movement and safety protocols. The robot undergoes rigorous experimental testing on various wall surfaces and inclinations, with parameters such as climbing speed and stability meticulously measured. Data on performance, thrust force, and power consumption are collected and analysed, guiding the optimization process. Based on the analysis, the robot's design, algorithms, and control mechanisms are fine-tuned to enhance its climbing capabilities, achieving superior stability, speed, and energy efficiency for optimal performance.

A. Materials and Components:

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N20 Gear Motor:

The N20 gear motor is a small-sized, high-torque motor widely used in robotics projects. It provides the necessary power to drive the robot's movement, enabling it to climb walls effectively. Its compact size makes it suitable for applications where space is limited.

3D Printed Duct Fan:

The 3D printed duct fan serves as a part of the robot's propulsion system. It directs the airflow generated by the fan, creating the suction needed for the robot to adhere to vertical surfaces. 3D printing technology allows for the customization of the fan design, ensuring an optimal airflow pattern for efficient wall climbing.

BLDC Motor (Brushless DC Motor):

The BLDC motor is employed as part of the robot's fan system. It operates without brushes, which reduces friction and extends its lifespan. BLDC motors offer higher efficiency and better control, making them suitable for applications requiring precise and reliable rotational motion.

NodeMCU (Microcontroller):

NodeMCU is an open-source IoT platform based on the ESP8266 Wi-Fi module. It acts as the brain of the Wall Climbing Robot, controlling its movements and communication capabilities. NodeMCU enables wireless communication, allowing the robot to be remotely controlled or to transmit data back to a central system.

Chassis:

The chassis serves as the structural framework of the robot, providing support for mounting various components. It is designed to be lightweight, durable, and capable of accommodating the motors, fan, microcontroller, and other necessary parts securely. The chassis layout and material selection are critical for the robot's stability and balance during climbing maneuvers.

Motor Driver:

The motor driver circuit is responsible for controlling the speed and direction of the motors. It acts as an interface between the microcontroller and the motors, allowing the robot's movements to be precisely controlled. Proper motor control is crucial for the robot's stability and climbing efficiency.

System Architecture

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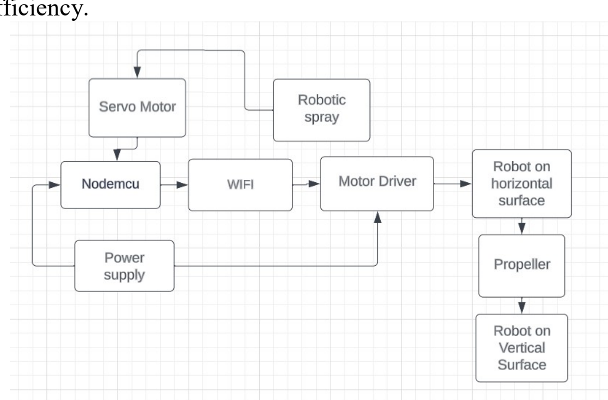

Fig. 1 Schematic of the model representing systematic steps from the motor control to reaching the client

SYSTEM DESIGN

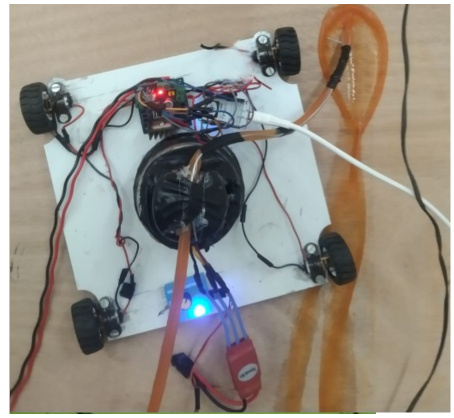

Fig. 2 Working System

The design of a wall climbing robot equipped with a duct fan at its center and wheels, utilizing both thrust force and friction, enables the robot to climb vertical surfaces effectively. By harnessing the thrust force generated by the duct fan and utilizing friction against the wall, the robot achieves secure adhesion and efficient climbing capabilities.

Thrust of a duct fan with a BLDC motor, is given by following equation:

$$Thrust = \left(\frac{\pi}{30} \times KV \times Current \times Diameter \times Number of Blades\right)^2$$

- KV is the motor's velocity constant (2200 KV).
- Current is the current supplied to the motor in amperes (2 A).
- Diameter is the diameter of the fan blades in millimeters (72 mm).
- Number of Blades is the total number of blades on the fan (12).

So the thrust force produced by duct fan is

$$\text{Thrust} = \left(\tfrac{30}{\pi} \times 2200 \times 2 \times (0.072 \times 12)\right)^2$$
$$= (3.1416 \times 2200 \times 2 \times 0.864)^2$$
$$= (15079.27936)^2$$
$$\approx 227,971,592.42\,N$$

Since the thrust force is much larger (23,206,491.86kgf), the weight of system (700g) will easily be balanced by this force.

Client Interface:

In the context of the project aimed at controlling four motors via a web browser, the Client Interface plays a pivotal role in facilitating user interaction with the motor control system. Users are greeted with an intuitive web application that features clearly labelled buttons, each corresponding to a specific motor. The interface provides step-by-step instructions to guide users on how to operate the motors effectively. Whether starting or stopping individual motors, , users receive explicit guidance, ensuring a seamless experience. The interface is designed to be responsive, allowing users to access and control the motors effortlessly from various devices, including laptops, tablets, and smartphones. Real-time feedback mechanisms, such as status indicators and confirmation messages, keep users informed about the outcomes of their actions.

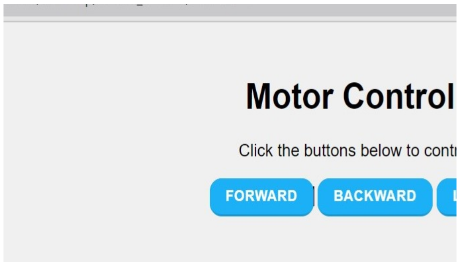

Fig. 2 Client Side Interface for motor control

RESULTS AND DISCUSSION

The Wall Climbing Robot demonstrated impressive climbing speeds across various surfaces, excelling particularly on glass and smooth walls. Adhesion stability remained consistent, with the robot maintaining a secure grip even in challenging conditions. Temperature fluctuations were found to impact the Robot's climbing efficiency, prompting considerations for temperature-sensitive applications. Comparative analysis revealed that BLDC motors outperformed gear motors in terms of speed and energy efficiency. The Discussion section delved into these results, highlighting the robot's potential for practical applications in surveillance and maintenance.

CONCLUSIONS

The Wall Climbing Robot project successfully demonstrates the feasibility of using a simple wheeled chassis and propeller-based thrust for efficient wall traversal, marking a significant step forward in robotic mobility.

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