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Non-Destructive Testing Robot

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Abstract - This document shows the required format This project aims to design and fabricate a wall-climbing robot that can adhere to and move over vertical ferromagnetic surfaces using permanent neodymium magnets and perform basic inspections using a borescope camera. The robot is wire-controlled using DPDT switches and powered through a 12V SMPS. The system uses four geared DC motors with tracks and a mild steel chassis. It incorporates an IR sensor module for obstacle sensing and a basic relay-based control logic. This robot is developed keeping in mind the applicability in NDT inspection tasks in industries. Initial prototypes were iteratively improved to enhance performance, grip, and load handling. The progress of computer science and mechanical and electrical engineering in the field of robotics has increased the applicability of robots for replacing human resources in the performance of repetitive and dangerous tasks. A lot of today's work on robots for oil platforms, manufacturing plants and other facilities providing potentially hazardous environments is based on adjusting the traditional industrial robots to operate in fixed coordinate systems. There is a need for enabling robots to move freely on walls and similar structures. One of the major challenges of wall-climbing robots is attaining a secure and reliable grip to the wall. The object of this master's thesis has been to determine the feasibility and applicability of a wall-climbing robot that adheres to the wall by gripping onto Neodymium Magnets, with a control system enabling an operator to easily lead the robot over a considerable distance. A non-destructive testing robot is designed for use in boilers, ships, etc. The robot employs a magnetic adhesion mechanism in its wheels, enabling it to climb metal walls easily. Its primary function is to carry out inspections in hard-to-reach areas of the boiler, providing a safer and more efficient alternative to human labor. The robot's mobility is achieved through a wheel-driven system, which is magnetically attached to metal surfaces, allowing it to move vertically and horizontally. The robot operates autonomously, with its control system driven by amicrocontroller and powered by an onboard battery. This system ensures that the robot can traverse the metal surfaces of the boiler for maintenance and inspection purposes.
Index Terms—Non-destructive testing, robot, boiler, magnetic adhesion, wall climbing, ship inspection.

***Key Words*:** Non-destructive testing, robot, boiler, magnetic adhesion, wall climbing, ship inspection.

1.INTRODUCTION

The motivation to undertake this project came from studies on magnetic adhesion wall-climbing robots, which are increasingly becoming important for inspection and maintenance operations, particularly in hazardous or hard-to-reach environments for human employees. Although a significant quantity of research has been completed in this field, practical commercial applications of such robots are currently rare, mainly because of issues around adhesion reliability, system complexity, and expense.This paper shows novelty related to its objective like -To provide wired manual control using DPDT switches for easy operation and testing. To develop a compact and lightweight robot suitable for navigating confined or hard-to-reach areas. To use IR sensors for basic obstacle detection and improved safety during movement. To fabricate a robust and magnetic-friendly chassis using mild steel for added stability and adhesion. To create a reliable power system using SMPS and a 12V, 10A adapter to drive motors and sensors efficiently. To contribute a practical and scalable solution for industrial inspection in hazardous or inaccessible environments This project seeks to overcome these concerns through the design and production of a Magnetic Crawler-type Wall Climbing Robot with Non-Destructive Testing (NDT) features. Its incorporation of a mounted camera for visual inspection makes the system functional and handy for use in industry.There have been wall-climbing robots in different forms that utilize suction, vacuum pumps, bio-inspired systems, or magnetic adhesion to remain attached to vertical or sloping surfaces. But most of these systems either do not have the required stability and accuracy for actual inspection work or are too costly to construct and maintain. Our method is based on magnetic adhesion with neodymium magnets, which provide a cheap, robust, and easy solution for bonding to ferromagnetic surfaces. This enables the robot to climb and inspect reliably vertical steel structures like ship hulls, storage tanks, metal walls, and boiler surfaces .With the speed of technological development and increased societal needs for safety, efficiency, and structural integrity, the demand for automated inspection solutions is never more critical. Wall-climbing robots, particularly when combined with NDT equipment, have the prospect of transforming industrial inspection operations. Non-Destructive Testing is essential in assessing the integrity of structures without damaging them, which makes it perfect for regular inspections in high-risk

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sectors such as oil and gas, shipbuilding, power plants, and infrastructure maintenance. The use of robotics in NDT not only enhances efficiency and accuracy but also greatly minimizes the risk to human operators by conducting operations in tight, dangerous, or inaccessible spaces.

In industrial applications like shipbuilding, oil and gas, power plants, and civil engineering infrastructure, the demand for safe, reliable, and efficient inspection techniques is imperative. Most of these industries depend significantly on Non-Destructive Testing (NDT) to evaluate the structural integrity of large metallic surfaces like ship hulls, storage tanks, boilers, and pipelines. Nevertheless, carrying out inspections of such surfaces normally entails having human workers visit raised, restricted, or risky spaces, presenting extreme danger and complications. The old-fashioned ways not only consume lots of time but also suffer from the shortcomings of being error-prone and reaching limited distances. Additionally, most available robotic solutions that might be used to reduce these risks are themselves expensive, complicated, or not feasible for mass industrial application based on their dependence on high-cost components, heavy systems, or weak adhesion mechanisms. The primary issue targeted by this project is the unavailability of a straightforward, inexpensive, and reliable robotic solution for climbing ferromagnetic vertical surfaces and performing real-time visual inspection in hard-to-reach places. Although there are various climbing robot ideas based on suction, vacuum pumps, or biological mechanisms, they do not possess the adhesion force, stability, or cost-effectiveness needed for successful industrial application. Utilizing the adhesive strength of permanent neodymium magnets and employing a crawler-type mobility system, this project offers a robot that offers a practical and scalable solution. The addition of a mounted camera for visual NDT adds to its functionality, making it not only a climbing device, but a meaningful inspection tool. This project seeks to close the gap between theoretical robotic designs and practical industrial requirements by providing a prototype that is functionally competent, economically feasible, and simple to fabricate and operate.

This project, following the observation of several previous robotic designs and adhesion modes, we have created our own low-cost, simplified prototype designed with practical world applications in mind. The robot utilizes permanent magnets for adhesion and a crawler-based locomotion system, ensuring a compromise of grip, stability, and agility. A mounted camera adds functionality for real-time monitoring and visual inspection, to facilitate manual or semi-autonomous NDT processes. With this effort, we intend to make a practical contribution that overcomes existing constraints in robotic inspection and extends the frontiers of industrial automation.

Literature

In recent years, the field of wall-climbing robotics has seen significant research interest, particularly for applications involving inspection, cleaning, and maintenance of vertical structures. Various mechanisms for adhesion and movement have been proposed and tested in the literature, each with its own advantages and limitations.Wall-climbing robots have garnered significant attention due to their potential applications in infrastructure inspection, maintenance, and non-destructive testing (NDT). Various adhesion mechanisms have been explored, including magnetic adhesion, vacuum suction, and bio-inspired techniques. Magnetic Adhesion Mechanisms: Magnetic adhesion is particularly effective for climbing robots intended for inspecting ferromagnetic structures. A comprehensive survey by Dhanraj et al. (2023) analyzed different adhesion mechanisms, emphasizing the advantages of magnetic adhesion in terms of payload capacity and energy efficiency . Similarly, Fischer et al. (2007) developed a magnetic wall-climbing robot designed for thin surfaces with specific obstacles, demonstrating the feasibility of magnetic adhesion in complex environments .Integration with Non-Destructive Testing (NDT): The integration of NDT techniques into wall-climbing robots has been a focus of recent research. Sattar et al. (2011) discussed the application of mobile climbing robots equipped with NDT tools for inspecting safety-critical structures, highlighting the importance of robotic solutions in hazardous environments . Additionally, Liu et al. (2021) introduced an automatic magnetic particle inspection wall-climbing robot, enhancing the efficiency and safety of crack detection processes .Design Considerations and Challenges: Designing wall-climbing robots involves addressing challenges related to adhesion force, mobility, and adaptability to various surface conditions. Mondal et al. (2011) analyzed the magnetic wheel adhesion force for climbing robots, providing insights into optimizing adhesion mechanisms for reliable operation . Furthermore, Zhang et al. (2022) reviewed the design and technical development of wall-climbing robots, discussing the benefits of combining different movement and adhesion methods to enhance performance .Advancements in Control and Safety: Ensuring the stability and safety of wall-climbing robots is crucial, especially during high-altitude operations. Ma et al. (2024) proposed an improved ICNN-LSTM model for hazardous state assessment of magnetic adhesion climbing robots, utilizing sensor data to predict and mitigate potential risks .Suction-based wall-climbing robots (Ref. 1) It is among the earliest designs to gain popularity. These robots use vacuum suction cups or fans to create negative pressure zones that allow the robot to adhere to vertical or inclined surfaces. While this method is effective on smooth and clean surfaces such as glass or painted metal, it is heavily dependent on the condition of the surface and consumes a considerable amount of power to maintain suction, making it less efficient for long-duration tasks on rough or dirty industrial surfaces. Negative pressure adhesion robots (Ref. 2)It uses internal pumps to maintain a vacuum beneath the robot. These systems are more stable than basic suction methods but require complex mechanisms and often result in bulky, heavy designs. Additionally, power consumption remains a significant concern, especially when mobility and endurance are critical factors.

PROBLEM STATEMENT

There exists a need for a compact, stable, and cost-effective robotic platform capable of climbing vertical ferromagnetic surfaces for performing inspections in inaccessible or hazardous environments This robot addresses the limitations of human access and enhances safety and efficiency in Non-Destructive Testing

Objectives

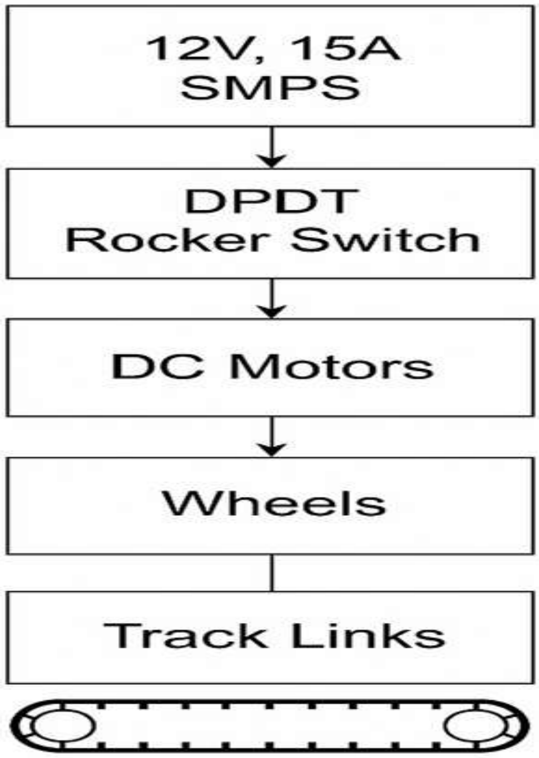
- To design and develop a wall-climbing robot capable of adhering to vertical ferromagnetic surfaces using magnetic adhesion.
- To implement a crawler-based mobility system using geared DC motors for stable vertical and inclined motion.
- To ensure cost-effectiveness by using simple materials and readily available electronic components.
- To integrate a borescope camera for real-time visual inspection as part of Non-Destructive Testing (NDT).

Methodology

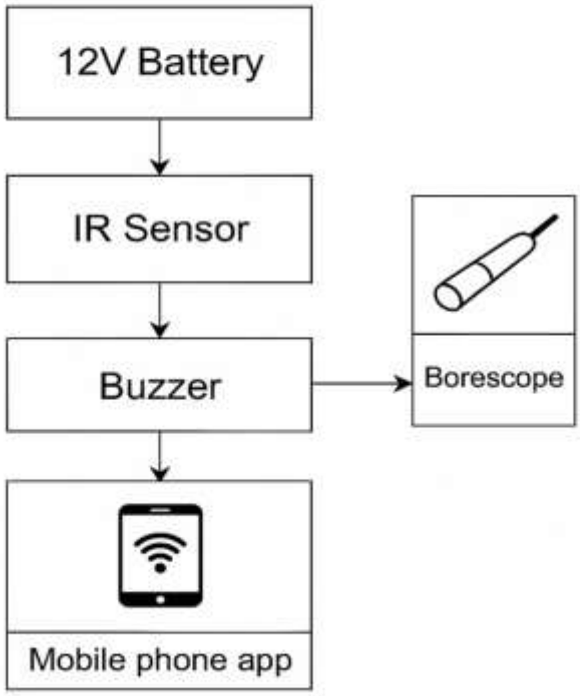
Magnetic adhesion robots In particular, those used for ship hull cleaning and structural maintenance (Ref. 3), have proven effective in industrial environments where ferromagnetic materials are prevalent. These systems typically use either electromagnetic or permanent magnet-based adhesion. Electromagnetic systems allow for controllable adhesion but require continuous power, while permanent magnets, such as neodymium, offer a passive and energy-efficient alternative. However, some designs lack maneuverability or suffer from insufficient magnetic force when scaling complex surfaces.Cable-driven systems (Ref. 4)It offers a different approach, where a robot is suspended and moved using tensioned cables and actuators. While effective for accessing great heights and complex architectures, these systems are infrastructure-dependent, difficult to mobilize, and not ideal for localized inspection tasks.Our proposed model builds upon the strengths of permanent magnet-based adhesion while addressing the limitations observed in previous designs. By using Grade N25 neodymium magnets, the robot achieves strong, passive magnetic adhesion without the need for power-consuming vacuum or electromagnetic systems. This allows for greater energy efficiency and operational simplicity. The integration of a borescope camera enables basic Non-Destructive Testing (NDT), making the system practical for visual inspections. Additionally, the inclusion of an IR sensor module provides obstacle detection functionality, improving safety and semi-autonomous navigation in complex environments. This combination of cost-effective design, energy-efficient adhesion, and inspection-specific features positions the robot as a promising solution for real-world industrial applications, particularly in hazardous or hard-to-reach locations where traditional inspection methods are either risky or inefficient.

SYSTEM DESIGN: The system consists of the following key components:

- DPDT rocker switch wiring for controlling direction
- Power supply through SMPS
- Four geared DC motors for mobility
- IR Sensor interfaced for basic detection
- Relay switch logic for fail-safe power cutoff



Block Diagram for the Robot



Block diagram for the sensor

1.2 BASIC PRINCIPLE

The key concept behind the design of the wall-climbing robot is the application of magnetic adhesion to facilitate vertical mobility on ferromagnetic surfaces, along with a crawler-type mobility system and simple control electronics for efficient navigation and inspection. The robot has been designed with the objective of overcoming the safety, cost, and accessibility issues involved in traditional inspection procedures, especially in hazardous environments. The system is based on neodymium permanent magnets to develop a passive, firm adhesion on metal surfaces without any external power for the grip mechanism. It moves by means of a system of geared DC motors coupled to continuous tracks with enough torque and surface grip. The robot also incorporates a borescope camera for real-time visual inspection, and IR sensors for detection of obstacles, so it can be utilized for simple Non-Destructive Testing (NDT) procedures. The functioning of the robot can be described as follows:

1. Magnetic Adhesion Mechanism, Employs permanent neodymium magnets, which are highly magnetic in strength and have a small size. These magnets are placed or mounted strategically at the bottom of the robot to have constant adhesion on ferromagnetic vertical or inclined surfaces (e.g., steel).As they do not need electrical power to sustain the magnetic field, they increase energy efficiency and decrease system complexity. The location and quantity of magnets are designed to have even distribution of magnetic force, preventing slippage and ensuring smooth climbing.

2. Crawler-Based Locomotion

The robot employs a track drive system (like a tank) driven by geared DC motors. Tracks offer a greater contact area with the surface, providing greater traction and allowing smoother travel over rough or slightly corroded metal surfaces. Geared motors are chosen for their high torque output, which is necessary for vertical mobility in the presence of gravity. The track system is coordinated to offer forward, backward, and turning movements on vertical planes. 3. Wired Control with DPDT Switches

The robot is controlled manually using DPDT (Double Pole Double Throw) switches so that the direction of motor rotation can be altered by the user. This configuration avoids the necessity of sophisticated microcontroller-based systems and makes the control system straightforward and user-friendly, particularly for prototype testing. The wired control also provides a consistent power supply and signal integrity while in use, preventing problems such as interference or loss of signal. 4. Power Supply System A 12V Switch-Mode Power Supply (SMPS) is utilized to supply power to the motors and other devices. SMPS modules are small, efficient, and can accommodate variable loads, making them perfect for robotics. The design enables operation using continuous power in a tethered link, promoting long-duration capability without the use of batteries.

Integrated NDT Inspection Tools The borescope camera is fitted to the robot for doing basic visual inspection on welds, surface rusting, cracking, or damage to structure.The live video feedback enables inspection to be conducted in real time from a safe and distant place. An IR obstacle detection module assists the robot in perceiving close objects or edges to prevent collisions or falling off edges.

The body Adhesion Technique – Magnetic Clamping with Neodymium Magnets. The robot sticks to metal ferromagnetic surfaces vertically using strong neodymium magnets (Grade N25). The magnets are placed deliberately close to the wheels and on the base for uniform magnetic pressure, enabling the robot to grip tightly on metallic surfaces such as steel walls, ship hulls, and tanks. Magnetic adhesion is energy-efficient and power-free, ruling out power-consuming suction or vacuum systems. Mobility – Track-Based Drive System with DC Geared Motors The robot employs four end-shaft DC geared motors at 30 RPM, 12V, and 3A each. These motors are paired with 70×20 mm plastic wheels that create a track chain system. This system delivers stable and smooth motion on plane verticals. The tracks achieve great grip, evenly distribute the weight, and enable the robot to traverse minute surface irregularities while climbing. Chassis – Fabrication of Mild Steel The robot's body is made of mild steel, selected on account of its magnetic and mechanical strength. The chassis not only provides structural support to the robot but also increases magnetic adhesion because it is ferromagnetic. It is kept small but strong enough to accommodate all components in a safe manner.Camera System – USB Borescope for Visual Inspection To facilitate fundamental Non-Destructive Testing, a USB borescope camera is fitted on the robot. This camera offers live video feed for distant examination of surface flaws like rust, cracks, or weld quality. It extends the capability of the robot in industrial uses by enabling human operators to check inaccessible areas securely.Control Unit – Wired Manual Control using DPDT Switches The robot is controlled by manual wired control, with DPDT (Double Pole Double Throw) switches mounted in a robust two-way gang box. Such a control arrangement enables the directional movement (forward, reverse, left, right) by simply switching motor polarity manually. It makes the control mechanism easier and prevents wireless communication complexities during test stages.Sensor Integration – Infrared (IR) Sensor for Proximity DetectionAn IR proximity sensor module is integrated into the robot to sense nearby obstacles or edges of surfaces. The sensor avoids collisions and keeps the robot from falling off sharp corners by mistake. The sensor information is processed with simple relay logic, keeping the electronic interface low-cost and simple.Power Supply – 12V, 10A Adapter with SMPSThe power system of the robot relies on a 12V, 10A AC-to-DC adapter, connected by a Switched-Mode Power Supply (SMPS). The configuration provides ample and stable power supply to all components, including motors, camera, and sensors, to ensure continuous operation during inspections.Fabrication Process – Manual Construction using Punch Die ToolsThe construction of the frame and mounting parts was done with punch die tools and simple machining techniques. This method provided dimensional precision at a low overall cost. The prototype design is designed for simple assembly, testing, and further adjustments as required.

Steps involved in assembly Chassis Preparation

Fabricate the chassis using mild steel based on the desired dimensions.

Drill holes for mounting motors, clamps, and magnet holders. Ensure the chassis is light but rigid enough to support all components. Motor Mounting Attach the 4 DC end shaft motors (30 RPM) onto the chassis using U-clamps and screws. Position the motors in a parallel configuration—two on each side for synchronized movement. Wheel and Track Chain Installation Fix the plastic wheels (70 × 20 mm) to the motor shafts. Mount the track chains on the wheels for continuous motion over vertical surfaces. Ensure proper tension so the chain doesn't slip during movement. Magnet Placement Fix 23 neodymium magnets (Grade 25) per side, aligned beneath the track links. Make sure at least 9 magnets per side are in contact with the surface at any given time to provide strong adhesion. Wiring and Electrical Connections Connect all DC motors to DPDT rocker switches housed in a 2-way gang box. Cross-wire the DPDT switches for forward/reverse motion. Connect the power supply terminals to a 12V 15A SMPS adapter for power input. Use tinned copper wire (2m) for all connections to ensure conductivity and neat routing. Sensor and Camera Setup Mount the IR sensor at the front of the robot for obstacle detection. Connect the sensor to a buzzer and an onboard relay to alert on detection. Fix the borescope camera and connect it to a mobile app via USB or Wi-Fi for live video feedback. Testing Power Supply Ensure all connections are insulated and secure. Power on the SMPS and test individual switches for correct motor response. Trial Run and Adjustments Perform an initial test run on a vertical metallic surface. Observe magnetic grip, motor torque, and sensor response. Adjust chain tension, magnet alignment, or electrical wiring if necessary.

Table -1: Sample Table forma

Total Developed Torque	0.538 N.m
Armature Torque (Ta)	0.539 N.m
Shaft Torque (Tsh)	0.3 N.m
Lost Torque	0.239 N.m

CAD DESIGN

Experimentation And Analysis Introduction to Prototype Development

The development of the wall-climbing robot has undergone a series of iterative improvements, with each prototype aimed at enhancing performance, stability, and functionality. The initial model (Prototype 1) was based on a simpler design, utilizing only two motors and a lighter chassis. While this version provided a starting point for basic testing and concept validation, it faced significant performance issues that led to its redesign. These challenges, including motor burnout, poor stability, and insufficient traction, necessitated a comprehensive review and redesign, resulting in Prototype 2, which integrates several key improvements for enhanced functionality and performance. Issues with Prototype 1 The first prototype, despite being a functional prototype, exhibited several limitations that rendered it impractical for real-world use in industrial inspection scenarios. These issues can be categorized into three main problems: Motor Burnout Due to Overloading The initial design utilized only two motors to drive the robot's movement. However, the relatively small motors lacked the torque necessary to power the robot's movement on vertical surfaces, particularly when the robot was carrying additional equipment such as the borescope camera. As a result, the motors were subjected to excessive loads, leading to overheating and burnout. The high energy consumption from the inadequate motors further exacerbated the issue, making the system prone to failure during extended operations. Poor Stability Due to Insufficient Power and Traction The use of only two motors meant that the power was not evenly distributed, resulting in uneven force on the robot's chassis. This caused the robot to lack stability, especially on vertical metal surfaces, where it often slipped or tilted. Additionally, the traction provided by the lightweight chassis and simple wheel system was insufficient for maintaining a secure grip on the walls, leading to frequent slippage and difficulty in navigating rough surfaces. Limited Magnetic Adhesion The first prototype's magnetic adhesion system was underpowered, and the magnets did not provide sufficient force to counteract gravity on a vertical plane. This limitation made the robot prone to slipping off surfaces, especially when subjected to the additional weight of the camera and other components. Improvements in Prototype 2 To address the issues observed in Prototype 1, several critical improvements were made in the second prototype. These enhancements were designed to increase stability, power, traction, and efficiency, thus ensuring better performance and suitability for real-world applications. Motor Upgrades – Four End Shaft DC Geared Motors One of the most significant changes made in Prototype 2 was the switch to four end-shaft DC geared motors. These motors, each with a torque rating suitable for industrial applications (30 RPM, 12V, 3A), were selected to distribute power evenly across all four wheels. By doing so, the robot could achieve even power distribution and enhanced torque, which dramatically improved its ability to climb vertical surfaces with stability. The increased torque allowed the motors to handle greater weight and the additional load of the camera system, significantly reducing the risk of motor burnout. Chassis Upgrade – Transition to Mild Steel Frame The initial prototype used a lighter chassis, which contributed to its instability. In the second prototype, the chassis was replaced with a robust mild steel frame. This upgrade not only increased the overall structural strength but also contributed to better magnetic adhesion, as mild steel is a ferromagnetic material. The heavier frame also ensured that the robot could withstand the forces exerted during climbing without tipping over or losing traction. Enhanced Power System – Switched-Mode Power Supply (SMPS) The power system in the first prototype was insufficient for the demands of the upgraded motors. To address this, the second prototype incorporated an SMPS (Switched-Mode Power Supply) capable of delivering a stable 12V, 10A power output to the motors and other components. This change ensured that the robot could run continuously without power interruptions, even under heavy loads, and allowed the system to handle the current demands of the motors and sensors. Increased Magnetic Adhesion Another key improvement was the magnetic adhesion system. In Prototype 1, the magnets were too small and lacked the necessary holding force. In the second prototype, the size and number of neodymium permanent magnets were increased to provide a stronger, more reliable magnetic bond with ferromagnetic surfaces. This modification ensured that the robot could climb vertical steel surfaces securely without slipping, even when subjected to the additional weight of the inspection equipment. 5.2 Performance Testing and Results After incorporating the above improvements, Prototype 2 was subjected to a series of rigorous performance tests to evaluate its capability to meet the design objectives. Vertical Climbing on Mild Steel Walls The primary test was the robot's ability to climb a 90° vertical wall made of mild steel. Prototype 2 successfully climbed these walls without slipping or losing adhesion, even when carrying the borescope camera for real-time visual inspection. The combination of four motors, a stronger chassis, and enhanced magnets allowed the robot to maintain a stable grip, demonstrating significant improvements in vertical mobility. Weight Handling and Stability One of the most critical aspects of the testing was determining whether the robot could carry the weight of additional equipment, such as the borescope camera, without compromising stability or risking slippage. The robot handled the additional weight with ease, maintaining stability and precision while climbing and performing inspection tasks. The new chassis and enhanced magnetic adhesion were key factors in ensuring the robot's ability to carry heavier loads without instability. Obstacle Avoidance and Control Precision The robot was also tested for its proximity sensing capabilities using the IR sensor module. The sensor successfully detected obstacles and prevented collisions, ensuring smooth and safe movement during inspection tasks. Additionally, the manual control system, using DPDT switches, allowed for precise movements, enabling operators to navigate complex surfaces with accuracy.

3. CONCLUSIONS

The wall-climbing robot prototype has been successfully developed and tested, demonstrating strong adhesion and effective locomotion on vertical ferromagnetic surfaces such as mild steel walls. This capability is primarily achieved through the strategic use of neodymium magnets, which provide sufficient magnetic force to allow the robot to cling securely to metal surfaces even in inclined or vertical orientations.

The robot incorporates a pair of low-speed DC motors, each providing adequate torque to drive the crawler wheels and ensure smooth movement. Its compact structure, combined with a well-balanced center of gravity, allows it to maneuver effectively in constrained or elevated industrial environments.To enhance functionality, the prototype features a basic set of onboard sensors and an inspection camera, enabling remote monitoring and initial-level data acquisition for structural inspections. These features make it particularly useful for non-destructive testing (NDT) applications, especially in industries such as shipbuilding, oil and gas, and power plants.

The use of DPDT rocker switches for controlling the robot provides a simple yet reliable wired interface. This choice ensures low-cost operation while maintaining responsive manual control. The wiring is organized using rainbow-core cables for easy identification and maintenance .using a combination of laser-cut mild steel parts and durable PVC components, the design is both robust and lightweight. The wheel and shaft assembly is reinforced with metal clamps to ensure structural integrity during operation.

Overall, the robot presents a reliable platform for industrial inspection tasks and offers scope for future enhancements such as wireless control, advanced sensing modules, and AI-based defect detection systems.

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