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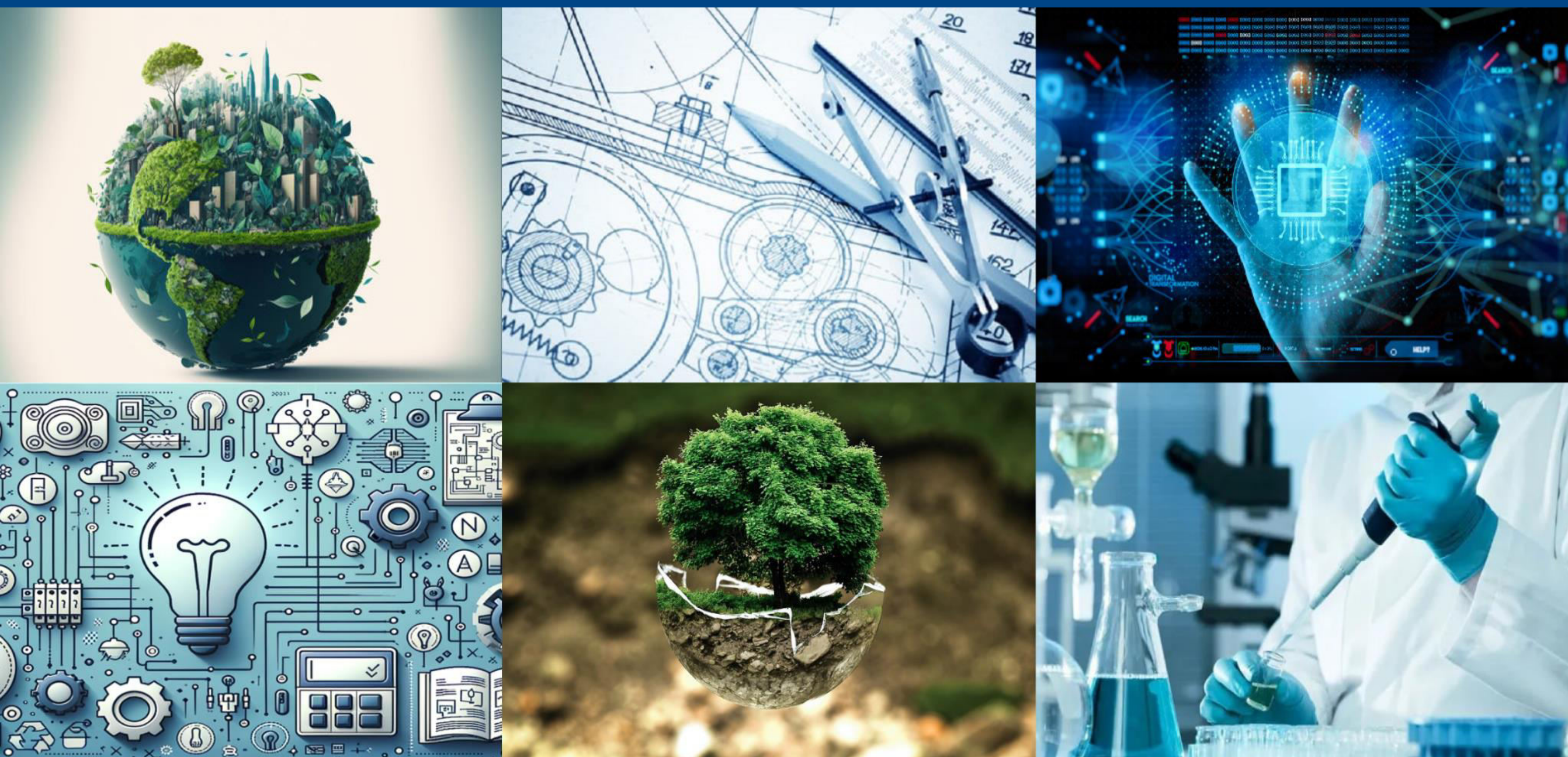

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Design and Development of Wall Climbing Robot for Structural Inspection

Mohamed Ralif, Mohammed Bilal, Soorya, P. Muniraja Chandra

Department of Mechanical Engineering, Aalim Muhammed Salegh College of Engineering, Avadi, Chennai, Tamil Nadu, India

ABSTRACT. In recent decades, skyscrapers, as represented by the Burj Khalifa in Dubai and Shanghai Tower in Shanghai, and various other structures with modern architecture have been built due to the improvements of construction technologies. Every building should undergo maintenance for eliminating defects arising from normal wear and tear which are carried out by humans. Inspection of inaccessible parts of structures is always a difficult task. With our Project titled Design and Development of Wall Climbing Robot for Structural Analysis, we are designing a robot that can be used for climbing walls and performing inspections and it is expected to replace the manual workforce in such activities, which are both hazardous as well as laborious work.

KEYWORDS. Adhesion Techniques, Negative Pressure Adhesion, Structural Inspection, Defect Detection, Vacuum Suction, Suction Field, Crack Detection, Linear Motion.

I. INTRODUCTION

In recent times there has been a great amount of high - rise buildings, skyscrapers, long bridges and industrial plants emerging all around the globe. These infrastructures are hard to monitor and it involves a high amount of human risk. Thus, this paper will be discussing on the remedy to neglect this human risk by introducing a wall climbing robot using Electric Ducted Fan (EDF). This robot is able to move on incline and vertical surfaces where it is unsafe or impractical for human interference. These robots are especially useful in situations where tall structures like skyscrapers, bridges, pipelines, nuclear power plants, and offshore platforms need to be inspected, maintained, and monitored.

The primary objectives of this paper are as follows:

- To analyze the design principles of wall climbing robotic systems.
- To classify existing adhesion mechanisms such as magnetic, vacuum, thrust and bio inspired systems.
- To review control and navigation methods, including wireless i.e. Bluetooth and autonomous systems.
- To identify technical and environmental challenges.
- To explore future scope or advancements in smart inspection, load optimization and AI – based detection.

II. LITERATURE REVIEW

According to Zhu, Yongqiang Zhu and Zhang (2024), there are multiple adhesion technologies that can be used for wall climbing robot and there is no single adhesion method that is universally ideal. These adhesion methods are selected based on the surface type, load and operational environment.

According to A. Brussels (2017), EDF suction performance must be experimentally calculated with respect to thrust, power consumption and suction efficiency.

According to Zhou and Li (2016). Rotor based flow or rotational flow absorption can create a strong negative pressure or vacuum suction field without the traditional vacuum pumps.

Qin (2022) and Chen (2025), both are conveying that ducted fans (EDF) can generate sufficient amount of thrust to press the robot against the wall and move and instead of separate adhesion and propulsion systems, same fans can be reused for air, ground, and wall modes.

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III. METHODOLOGY

3.1. Adhesion Technology

We will be using negative pressure (or) vacuum suction adhesion technology. We will be achieving this adhesion technology by using electric ducted fan (EDF). EDF will generate negative pressure when it pulls air through inlet and pushes through the outlet at a high velocity. This EDF works on Bernoulli's Principle i.e. when air velocity increases static pressure decreases, thus resulting in generation of negative pressure.

3.2. Mechanical Structure

For the structure of the robot, we will be placing the ducted fan at the center of the robot, thus creating an even field of vacuum which will enable the robot to push against the wall and move. Next, we will me using DC geared motors and wheels for the linear movement across the surface.

3.3. Microcontroller and Sensor

Microcontroller will be whole operational brain for the robot; thus, we will be using ESP32 because it has in-built Bluetooth and Wi-fi module, it reduces the wiring complexity, it is more suitable for a compact design and it saves power and cost.

And for the sensor we will be using a ESP32 camera module, it will be used for producing live video feed from which we can conduct structural inspection or structural monitoring.

3.4. Adhesion Force Equation

3.5. F adhesion = Δ Pressure X A Where,

- Δ Pressure – Pressure Difference
- A – Effective Suction Area

For the robot to make a successful climb it should satisfy the condition,

F adhesion ≥ W

Where, W – Weight of the robot.

3.5 Mechanical Design

For the designing the mechanical structure of the robot we will be using SolidWorks software and model will be focused on compact design and weight optimization.

3.6 Project Work Flow

The duration of the development of this robot will be over 12 weeks and weekly objectives are as follows:

Week 1 – 2: During this period, we will be conducting research on the available technologies for this robot and select the suitable technology. This period has been completed and result of the work done during this period is what this paper is all about.

Week 3 – 5: During this period, we will be sorting out the budget for the development of this robot and finalize the components that will be used throughout the development of this robot. Following this we will be purchasing the components that are required for the development of this robot.

Week 6 – 7: During this period, we will be engaged in the CAD modelling of the robot's mechanical structure. This will meet our objective of the development of the robot, i.e. compact design and weight optimization. The design will consist of two models for the robot and further development will be carried out on the successful model.

Week 8-10: During this period, we will be engaged in the electrical system of the robot. We will engage in identifying the ideal electric connection for our application, testing the connection, programming for ESP32 and ESP32 camera module, calibration of the camera module and working of the electric ducted fan (EDF).

Week 11 – 12: During this period, we will be conducting multiple test runs, check for operational errors (or) coding errors. Identify the suitable working model for the robot and conducting final test runs and obtain operational results.

These 12 weeks will summarize the design and development of the wall climbing robot using electric ducted fan (EDF) for structural analysis.

IV. FABRICATION AND DEVELOPMENT

4.1 CAD Modelling

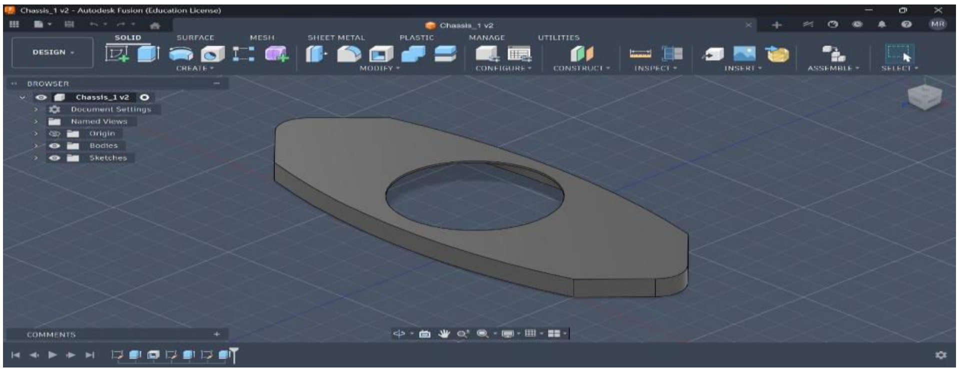

Fig 1 3D Modelling of Chassis 1

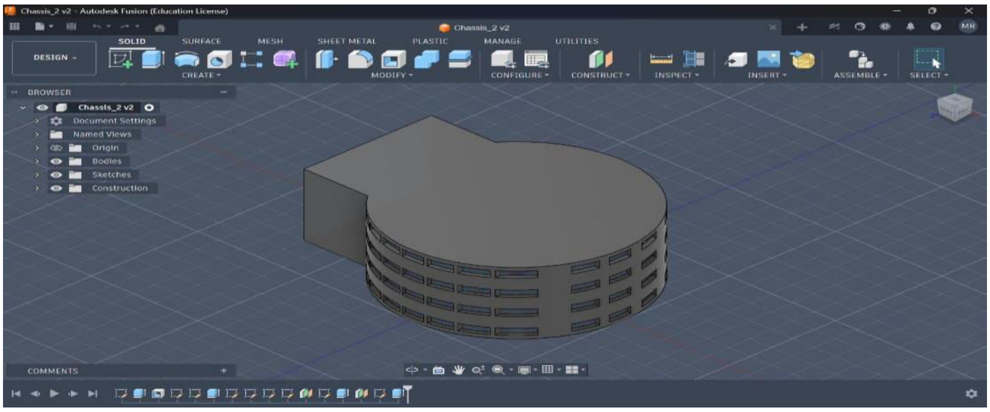

Fig 2 3D Modelling of Chassis 2

Fig 1 is the main body of the robot and is a casing for the robot and Fig 2 is a chamber-like structure which is assembled on top of chassis 1, through which air flows in and helps themotor to create vacuum field (or) negative pressure adhesion. This negative pressure adhesion helps the robot to move on vertical surfaces.

4.2 Circuit Diagram

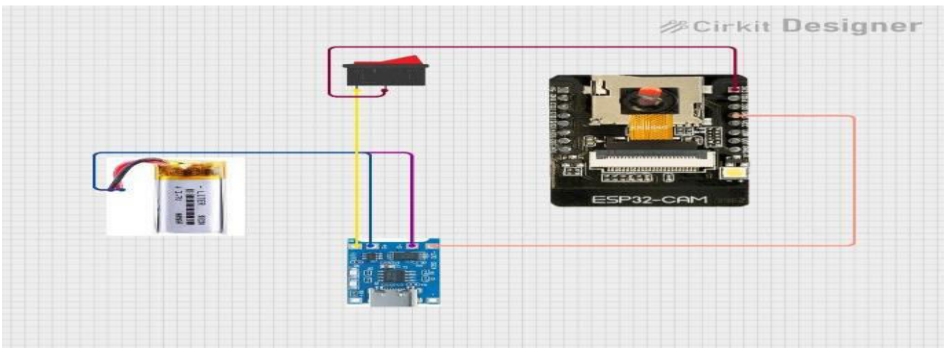

Fig 3. Circuit Design of ESP32-CAM connection

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ESP32-CAM is programmed in Arduino IDE environment through ESP32 microcontroller. Camera is powered through 3.7V Li-Po rechargeable battery which is connected to a TP4056 charging module and push switch. When the power is on then the hotspot from the ESP32- CAM module is turned ON by pressing the reset button. We connect the hotspot to a laptop or a smartphone and enter the IP address, once the IP address is connected, we get the page showing the life video feed of the camera.

4.3 Model Development

Fig 4 Top view of Robot

Fig 5 Front view of Robot

Fig 4 and Fig 5 display the top and front view of the robot after fabrication and assembly. The camera is placed on the robot as shown in Fig 5, in this way the camera is able to capture the surface and provide proper video feed which is used for detecting defects on the surface.

V. RESULTS AND DISCUSSION

Fig 7 Robot moving on a vertical surface

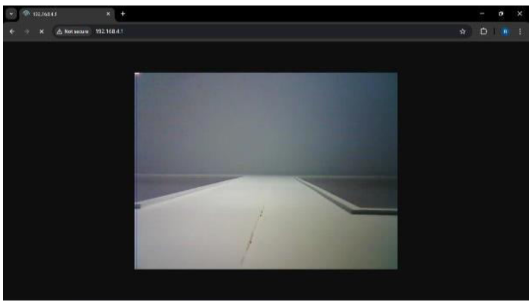

Fig 8 Crack image detected by the robot

Fig 8 shows that the robot is able to climb the vertical wall with the help of negative pressure adhesion, which is generated from high suction micro vacuum motor. Fig 9 shows that the ESP32-CAM is able to capture defects on the surface through the live video feed. Thus, wehave developed a wall climbing robot for structural inspection and able to capture defects from the surface.

VI. CONCLUSION

Wall climbing robots have become an effective solution for safe and efficient structural inspection of various infrastructures. In this paper we confront the issue and the reason for the development of this robot, design concepts, different types of adhesion mechanisms and control systems. We have also identified that there is no ideal adhesion mechanism and it varies depending on the environment and applications.Although these systems significantly enhance inspection safety and accessibility, challenges such as high energy consumption, limited surface adaptability, load constraints and adhesion reliability exist. Embedded controllers enable wireless operation and scalability toward intelligent inspection systems.

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