A REVIEW ON STAIRCASE CLEANING ROBOT

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Abstract: Cleaning staircases is a difficult and time-consuming task because of uneven steps and safety concerns. To reduce manual effort, different types of stair-climbing robots have been developed using various movement and cleaning mechanisms. This paper presents a simple overview of such systems, including wheel-based and tracked designs, along with cleaning methods like rotating brushes and vacuum systems. It also highlights important factors such as motor selection, stability, and weight distribution for proper movement. In addition, the role of sensors like ultrasonic and infrared sensors for obstacle detection and edge safety is discussed. Based on these studies, the concept of a staircase cleaning robot using a brush mechanism is explored. The main aim is to develop a system that is simple, cost-effective, and capable of cleaning stairs efficiently while maintaining stability and safety during operation.

Index Terms – **Staircase cleaning robot, stair-climbing mechanism, rotating brush, DC gear motor, sensors, edge detection, automation**

I. INTRODUCTION

Cleaning staircases is a common but challenging task in homes, offices, and public places because of the uneven structure of steps. Manual cleaning requires more effort and can sometimes be unsafe, especially while reaching edges or higher steps. With the development of robotics, many researchers have worked on designing stair-climbing robots to solve this problem. Different movement mechanisms such as wheels and tracks have been used, where wheels offer simplicity and low cost, while tracks provide better grip and stability. Studies also show that factors like motor torque, proper weight distribution, and frame design play an important role in smooth stair climbing. Along with movement, cleaning mechanisms such as rotating brushes and suction systems are used to remove dust effectively. Safety features are also important, and sensors like ultrasonic and infrared sensors help in detecting obstacles and edges to prevent accidents. However, many existing systems focus mainly on either movement or cleaning, and not both together in a simple and practical way. This paper focuses on combining these ideas to develop a staircase cleaning robot that uses a rotating brush for cleaning, along with a stable and efficient climbing mechanism, making the system useful for everyday applications.

II. LITERATURE REVIEW

"Design and Development of Stair-Climbing Robot," by A. Kumar and R. Singh (2018)

This work explains the design and development of a stair-climbing robot using basic mechanical components like motors, wheels, and a supporting frame. The authors mainly focus on proper motor selection, wheel size, and maintaining balance for smooth movement on stairs. They highlight that sufficient torque and correct weight distribution are important to avoid slipping or tilting while climbing. However, the design is quite simple and does not include advanced control systems or sensors, which limits its performance in real-time conditions. For a staircase cleaning robot, this study is very useful because it helps in building a stable base structure. A well-balanced robot ensures that the cleaning brush stays in contact with the surface, improving cleaning efficiency and making the system more reliable.[1]

"A Review on Staircase Climbing Robots," by S. Patel, M. Shah, and K. Patel (2019)

This study gives an overview of different types of stair-climbing robots, including wheel-based, tracked, and legged systems. The authors compare these designs based on working, advantages, disadvantages, cost, and complexity. Wheel-based robots are simple and affordable, tracked robots provide better grip, and legged robots offer flexibility but are more complex. One drawback of this study is that it is mostly theoretical and does not include detailed practical testing. For a staircase cleaning robot, this comparison is helpful in selecting the most suitable movement system. Since cleaning requires steady and continuous motion, a wheel or track-based system can be chosen to support smooth brush operation.[2]

"Tracked Mobile Robot for Stair Navigation," by J. Lee and H. Kim (2017)

This research focuses on a tracked robot designed for stair navigation. The tracked system improves grip and stability, especially on uneven or inclined surfaces, and reduces the chances of slipping. The authors explain that tracks help in achieving smoother and more controlled movement compared to wheels. However, tracked systems are generally more complex, heavier, and require more maintenance, which can increase the overall cost. In a staircase cleaning robot, this concept is useful because strong grip ensures that the robot remains stable while the brush is rotating. This leads to better cleaning performance, especially on rough or dusty stair surfaces.[3]

"Design of Smart Cleaning Robot Using Vacuum Mechanism," by P. Sharma and V. Gupta (2019)

This work explains cleaning mechanisms used in robots, mainly focusing on the combination of brushes and suction systems. The authors describe how rotating brushes loosen dirt and dust, while suction motors collect it effectively. They also discuss integration with control systems for better operation. A drawback of this approach is that suction systems increase power consumption and add complexity to the design. For a staircase cleaning robot, this study is very useful because it shows how a brush can be used as the main cleaning component. Even without a full vacuum system, a rotating brush can sweep dust efficiently, making the design simpler and more practical.[4]

"Sensor-Based Obstacle Detection and Avoidance System for Mobile Robots," by M. Rahman, S. Islam, and T. Ahmed (2019)
This study focuses on obstacle detection using ultrasonic sensors in mobile robots. It explains how sensors detect objects in front of the robot and help in avoiding collisions, improving safety and automation. The authors also discuss basic control methods used to respond to sensor inputs. However, ultrasonic sensors may not always detect very small or soft objects accurately, which can affect performance. In a staircase cleaning robot, this system is important because it prevents the robot from hitting obstacles like shoes or debris. It also protects the brush mechanism and ensures smooth and uninterrupted cleaning.[5]

"Edge Detection Techniques for Staircase Robots," by R. Verma and S. Yadav (2020)
This work explains edge detection techniques used in staircase robots to identify the boundaries of steps. This helps prevent the robot from falling and improves navigation accuracy. The authors show that proper edge detection increases safety during operation. A limitation is that the system may require careful calibration and can be affected by lighting conditions or surface irregularities. For a staircase cleaning robot, this feature is very important because while cleaning near the edge, the robot must remain safe. It allows the brush to clean close to edges without risk of falling, improving overall cleaning coverage.[6]

"Comparative Study of Wheel and Track Based Robots," by B. Kumar and D. Mishra (2020)
This study compares wheel-based and track-based robotic systems in terms of performance, cost, and application. Wheel systems are simple, lightweight, and cost-effective, while track systems provide better grip and stability on rough surfaces. The authors clearly explain the advantages and limitations of both designs. One drawback is that the study does not explore hybrid systems that combine both features. For a staircase cleaning robot, this comparison is very useful because the choice of movement system directly affects cleaning quality. A stable system ensures that the brush maintains proper contact with the surface, resulting in more effective cleaning.[7]

"Design and Development of a Low-Cost Stair-Climbing Robot Using DC Gear Motors," by R. Gupta and A. Verma (2021)
This study explains the design of a low-cost stair-climbing robot developed using easily available components. The authors focus on reducing cost while maintaining basic functionality like movement and stability. The robot uses simple DC gear motors and a compact frame design to climb stairs. They also discuss basic control methods for movement. A drawback of this work is that it lacks advanced features like sensors and automation, making it less suitable for complex environments. For a staircase cleaning robot, this paper is useful because it shows how a budget-friendly design can be created. It helps in developing a simple brush-based cleaning robot that is affordable and easy to build, especially for small-scale applications.[8]

"Microcontroller-Based Control System for Stair-Climbing Robotic Applications," by P. Reddy and S. Kumar (2020)
This research focuses on the use of microcontrollers in controlling stair-climbing robots. The authors explain how controllers like embedded systems can manage motor movement, direction, and speed. They also discuss integration with basic sensors for improved control. However, the system complexity increases when multiple components are connected, and programming becomes slightly difficult for beginners. In a staircase cleaning robot, this study is helpful because it explains how to control both movement and brush operation using a single controller (like ESP32). It ensures proper coordination between climbing and cleaning functions.[9]

"Implementation of IR Sensor-Based Safety System for Stair-Climbing Robots," by N. Sharma and V. Joshi (2022)
This paper focuses on safety features in stair-climbing robots, especially using infrared (IR) sensors for edge detection and obstacle sensing. The authors explain how these sensors help prevent falls and improve navigation accuracy. The system is designed to stop or change direction when a risk is detected. A drawback is that IR sensors can sometimes give inaccurate readings due to lighting conditions or reflective surfaces. For a staircase cleaning robot, this work is very useful because safety is critical while operating on stairs. It ensures that the robot can clean near edges using brushes without falling, improving both safety and efficiency.[10]

"Design and Analysis of Rotating Brush Mechanism for Robotic Cleaning Systems," by K. Singh and M. Tiwari (2021)
This study explains the use of rotating brush mechanisms in small cleaning robots. The authors describe how brush design, speed, and placement affect cleaning performance. They also discuss how dust is collected after brushing. The system is simple and effective for dry cleaning applications. A drawback is that it may not handle sticky or wet dirt effectively without additional systems. For a staircase cleaning robot, this paper is directly useful because it gives clear ideas about brush placement and operation. It helps in designing a system where the brush can effectively clean each step while the robot is moving.[11]

III. BLOCK DIAGRAM

This block diagram shows how a staircase cleaning robot works by connecting all components through a central control unit called the microcontroller. The system is powered by a supply source, usually a battery, which provides energy to the microcontroller, sensors, and motor drivers. The microcontroller acts as the main decision-making unit. It receives information from different sensors, processes it according to the programmed instructions, and then sends commands to the motors and other output devices.
The robot uses three important sensors to understand its surroundings and maintain stability. The ultrasonic sensor measures the distance to obstacles so the robot can avoid collisions. The IR sensor is mainly used to detect the edges of stairs, helping prevent the robot from falling. The gyro sensor monitors the robot's orientation and tilt, which is important for maintaining balance while moving on uneven stair surfaces. All these sensors continuously send their data to the microcontroller.
After processing the sensor inputs, the microcontroller controls the movement and cleaning actions through motor drivers. Motor drivers are used because the microcontroller alone cannot provide enough power to run motors. They take low-power control signals from the microcontroller and convert them into high-power output for the motors. One motor driver operates the DC gear motor, which is responsible for moving the robot. This motor is designed to provide high torque at low speed, making it suitable for climbing stairs. Another motor driver controls the DC brush motor, which is connected to the cleaning brush and is used to sweep

dust from the stairs. A servo motor is also connected to the microcontroller and is used for precise positioning tasks, such as adjusting the cleaning mechanism. In this way, the system works together by taking input from sensors, processing it in the microcontroller, and producing the required motion and cleaning action through motors.

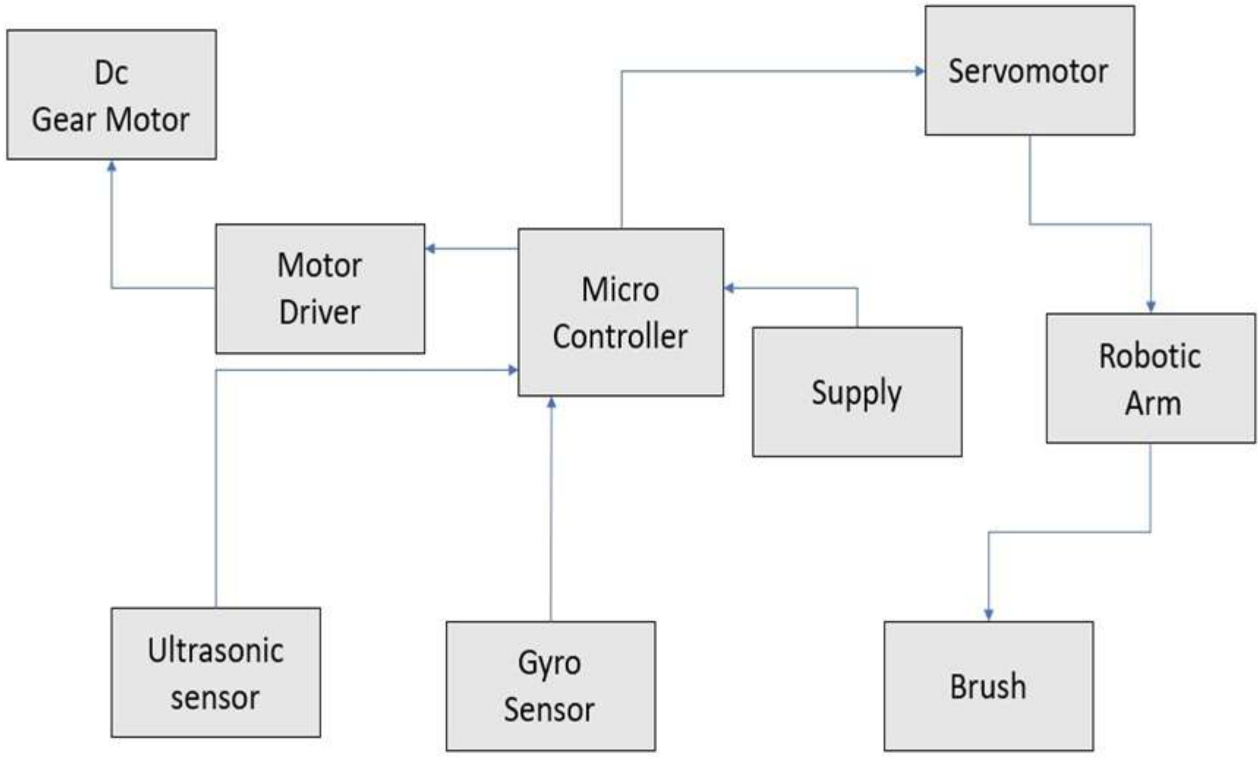

Fig. 1. Block diagram of the staircase cleaning robot system.

IV. WORKING PRINCIPLE

The staircase cleaning robot works by combining sensing, decision-making, and mechanical action to clean steps safely and automatically. The system is powered by a 12V battery, and a regulated supply is used to provide suitable voltage to different components. At the center of the system is the ESP32, which acts as the main controller and coordinates all operations.

The robot uses multiple sensors to understand its surroundings. An IR sensor is placed near the bottom of the robot to detect edges of the stairs. It works by checking the reflection of infrared light from the surface. When there is no surface ahead, the reflection is lost, and the system identifies it as an edge, helping to avoid falling. An ultrasonic sensor is used to detect obstacles in front of the robot by measuring the distance to objects. In addition, a gyro sensor helps in maintaining balance and stability while the robot is moving on inclined or uneven steps.

All the data collected from these sensors is sent to the ESP32, where it is processed using a programmed control logic. Based on this input, the controller decides the movement of the robot. For example, if an obstacle is detected, the robot can stop or change its direction, and if an edge is detected, it moves backward to ensure safety.

The movement of the robot is controlled using DC gear motors, which provide high torque required for climbing stairs. These motors are driven through a motor driver such as L298N Motor Driver or MOSFET Motor Driver, which helps in controlling speed and direction. Along with movement, a separate DC motor is used to operate the cleaning brush. The brush is connected to a rod and sweeps dust from the surface of each step as the robot moves forward. A servo motor may also be used to adjust the position of the cleaning mechanism if required.

The entire process runs continuously in a loop, where the sensors monitor the environment, the controller makes decisions, and the motors perform the required actions. This coordination allows the robot to move step by step, avoid obstacles, prevent falling, and clean the staircase effectively without human effort.

V. CONCLUSION

From the study of different research works, it can be understood that designing a staircase cleaning robot requires a proper balance between mechanical design, cleaning efficiency, and safety features. Wheel-based systems are simple and cost-effective, while track-based systems provide better grip and stability on stairs. Cleaning methods like rotating brushes are effective for removing dust and are easy to implement in a simple design. Sensors play an important role in improving safety by detecting obstacles and edges, which helps in preventing accidents during operation. However, many existing designs are either too complex or expensive, which limits their practical use. By combining simple components such as DC gear motors, a rotating brush mechanism, and basic sensors, an efficient and affordable staircase cleaning robot can be developed. Such a system can reduce human effort, improve cleaning performance, and provide a practical solution for maintaining cleanliness in staircases.

VI. FUTURE SCOPE

The future development of staircase cleaning robots can focus on improving performance, safety, and adaptability by addressing the limitations observed in existing studies. Most earlier designs rely on simple mechanical systems with limited sensing and control capabilities. In the future, more advanced control systems can be integrated to enable better decision-making and smoother operation in real-time conditions. This can include smarter algorithms that allow the robot to adjust its movement based on different stair sizes, inclinations, and surface conditions.

Another important area of improvement is the locomotion system. While wheel-based designs are simple and cost-effective, and tracked systems offer better grip, future designs can explore hybrid mechanisms that combine the advantages of both. This would help the robot maintain stability while also reducing complexity and maintenance issues. Lightweight materials and improved mechanical design can further enhance efficiency and reduce power consumption.

Sensor technology can also be upgraded to improve accuracy and reliability. Since ultrasonic and IR sensors sometimes fail to detect certain objects or are affected by environmental conditions, future systems can use a combination of sensors (sensor fusion) to achieve more dependable obstacle and edge detection. This will make the robot safer and more suitable for real-world environments where conditions may vary.

In terms of cleaning, current systems mainly depend on dry brush mechanisms, which are effective for dust but not for sticky or wet dirt. Future robots can include additional cleaning features such as mopping or limited suction systems while maintaining a balance between performance and power usage. Improving brush design and adaptability can also help in achieving better cleaning results on different types of surfaces.

Cost and usability remain important factors. While low-cost designs are beneficial, they often lack automation and advanced features. Future work can focus on creating affordable yet intelligent systems by optimizing component selection and simplifying programming. User-friendly interfaces and semi-autonomous or fully autonomous operation can make these robots more practical for everyday use.

Overall, the future scope lies in developing a more intelligent, efficient, and adaptable staircase cleaning robot that combines strong mechanical design, improved sensing, smarter control, and enhanced cleaning capability while still keeping the system economical and easy to use.

VII. REFERENCES

[1] A. Kumar and R. Singh, “Design and Development of Stair-Climbing Robot,” International Journal of Mechanical Engineering and Technology, vol. 9, no. 5, pp. 112–118, 2018.
[2] S. Patel, M. Shah, and K. Patel, “A Review on Staircase Climbing Robots,” International Journal of Engineering Research & Technology (IJERT), vol. 7, no. 4, pp. 345–349, 2019.
[3] J. Lee and H. Kim, “Tracked Mobile Robot for Stair Navigation,” IEEE International Conference on Robotics and Automation, pp. 1234–1239, 2017.
[4] P. Sharma and V. Gupta, “Design of Smart Cleaning Robot Using Vacuum Mechanism,” International Journal of Innovative Research in Science, Engineering and Technology, vol. 8, no. 6, pp. 1021–1026, 2019.
[5] M. Rahman, S. Islam, and T. Ahmed, “Sensor-Based Obstacle Detection and Avoidance System for Mobile Robots,” International Journal of Advanced Computer Science and Applications, vol. 10, no. 2, pp. 210–215, 2019.
[6] R. Verma and S. Yadav, “Edge Detection Techniques for Staircase Robots,” International Journal of Robotics and Automation, vol. 5, no. 3, pp. 55–60, 2020.
[7] B. Kumar and D. Mishra, “Comparative Study of Wheel and Track Based Robots,” International Journal of Engineering Science and Technology, vol. 11, no. 2, pp. 78–83, 2020.
[8] R. Gupta and A. Verma, “Design and Development of a Low-Cost Stair-Climbing Robot Using DC Gear Motors,” International Journal of Emerging Technologies in Engineering Research, vol. 6, no. 2, pp. 45–50, 2021.
[9] P. Reddy and S. Kumar, “Microcontroller-Based Control System for Stair-Climbing Robotic Applications,” International Journal of Electronics and Communication Engineering, vol. 8, no. 1, pp. 67–72, 2020.
[10] N. Sharma and V. Joshi, “Implementation of IR Sensor-Based Safety System for Stair-Climbing Robots,” International Journal of Advanced Research in Engineering and Technology, vol. 9, no. 3, pp. 120–125, 2022.
[11] K. Singh and M. Tiwari, “Design and Analysis of Rotating Brush Mechanism for Robotic Cleaning Systems,” International Journal of Mechanical and Production Engineering Research and Development, vol. 7, no. 5, pp. 88–93, 2021.

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