

Implementation of a ESP32-Based Staircase Cleaning Robot

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Abstract - Cleaning staircases is often a challenging and less preferred household task because it requires physical effort and involves safety risks when done manually. Although robotic cleaning systems are widely available today, most of them are mainly designed for flat surfaces and are not suitable for staircase environments. In this work, a simple and cost-effective staircase cleaning robot is proposed with basic safety and control features. The system is built using commonly available components such as a microcontroller, DC motors, and sensors. A rotating brush is used for dust removal, while an ultrasonic sensor helps in detecting stair edges to prevent falling. In addition, a gyroscope sensor is integrated to monitor tilt and maintain stability during movement. The overall structure is designed using lightweight materials to ensure low cost and easy construction. The main objective of this work is to develop a practical, affordable, and user-friendly solution that can be effectively used in everyday household environments.

Keywords: Staircase cleaning robot, low-cost system, ESP32, ultrasonic sensor, gyroscope, edge detection, stability.

I. Introduction

In daily life, maintaining cleanliness is important for ensuring hygiene and a healthy environment in homes, offices, and public spaces. While robotic vacuum cleaners have made floor cleaning more convenient, staircase cleaning still remains a difficult task due to uneven steps, sharp edges, and the challenge of maintaining balance while moving between levels. Because of these difficulties, staircase cleaning is mostly done manually, which requires physical effort and also carries a risk of slipping or falling. Although some robotic systems have been developed for stair climbing and cleaning, many of them are either costly or too complex for practical household use, and some lack proper stability control during operation. Therefore, there is a need for a simple, safe, and affordable solution that can work effectively in real conditions. This paper proposes a low-cost staircase cleaning robot that focuses on ease of use, basic safety features, and reliable performance using simple components such as sensors, motors, and a microcontroller.

II. Block Diagram

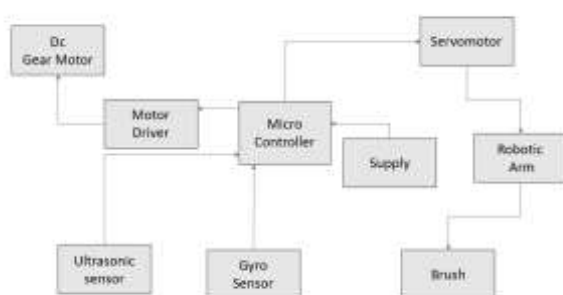


Fig : Block diagram of staircase cleaning robot

Fig 1: Block diagram of staircase cleaning robot

The staircase cleaning robot is developed by integrating multiple mechanical and electronic components that work together in a coordinated manner to achieve efficient movement as well as effective cleaning. The primary objective of the system is to provide a reliable solution for cleaning staircases, which are generally difficult to maintain using conventional methods. A DC gear motor is used as the main driving unit of the robot, as it is capable of delivering high torque at low speeds. This characteristic is particularly important for applications like stair climbing, where the robot needs sufficient strength to move upward while carrying its own weight along with the cleaning mechanism. The motor ensures smooth and controlled motion, which is essential for maintaining stability on uneven stair surfaces.

The operation of the DC motor is controlled using a motor driver, which acts as an intermediate interface between the motor and the control unit. The motor driver not only regulates the speed and direction of the motor but also supplies the required current, ensuring safe and efficient operation of the system. At the core of the robot lies the ESP32 microcontroller, which serves as the brain of the entire setup. It continuously receives input signals from various sensors, processes the data, and accordingly sends control signals to the motors and other actuators. This enables the robot to respond intelligently to different environmental conditions and perform its tasks in a synchronized manner. The entire system is powered by a rechargeable battery, which provides a stable and consistent voltage supply to all components. A reliable power source is crucial for uninterrupted operation, especially when the robot is navigating stairs and performing cleaning tasks simultaneously. For obstacle detection and safety, an ultrasonic sensor is incorporated

into the system. This sensor works by emitting sound waves and measuring the time taken for the echo to return, allowing the robot to detect obstacles in its path and avoid collisions. This enhances both the safety and efficiency of the robot during operation. In addition to obstacle detection, a gyro sensor is used to monitor the tilt and orientation of the robot. Maintaining balance while climbing stairs is a challenging task, and the gyro sensor plays a key role in ensuring stability by providing real-time feedback about the robot's position. Based on this feedback, necessary adjustments can be made to prevent tipping or imbalance. To achieve precise control of the cleaning mechanism, a servo motor is used for angular movement. The servo motor helps in accurately positioning the robotic arm, which holds the cleaning system. This robotic arm is designed to adjust according to the shape and structure of the staircase, allowing the cleaning brush to reach different areas effectively. The cleaning mechanism mainly consists of a brush that performs sweeping action to remove dust, dirt, and small debris from the surface of the stairs. The brush is mounted in such a way that it maintains proper contact with the stair surface, ensuring thorough cleaning. Overall, the coordinated functioning of all these components results in a system that is capable of performing staircase cleaning in a safe, efficient, and reliable manner. The design focuses not only on cleaning performance but also on stability, adaptability, and ease of operation, making it a practical solution for real-world applications.

Table 1: Component Specification

Sr.no	Component	Rating
1	Dc Gear Motor	12V, 60 RPM
2	Servo Motor	5V, 20Kg-cm
3	Wheels	-
4	Microcontroller ESP32	5V
5	Dual Motor Driver	8A
6	Battery	12V, 7Ah
7	Ultrasonic sensor	5m
8	Gyro sensor	-

III. Circuit Diagram

This circuit is for a staircase cleaning robot where a 12V battery supplies power, and 7805 regulators convert it to stable 5V for safe operation. The ESP32 microcontroller acts as the main control unit, sending signals to the L298 motor driver, which runs the DC gear motors for movement and stair climbing. Servo motors handle the cleaning mechanism by adjusting parts like brushes or suction. The ultrasonic sensor detects distance and obstacles, while the gyro sensor helps maintain balance. Capacitors are used throughout the circuit to ensure smooth and stable power, making the whole system work reliably together.

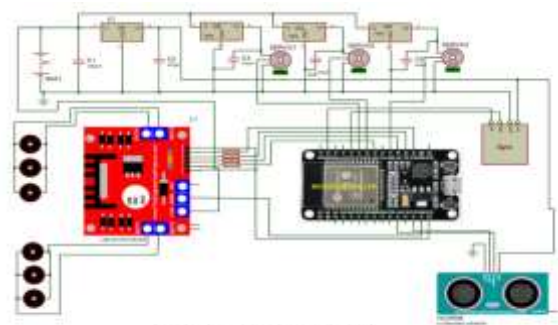


Fig: Circuit diagram of staircase cleaning

Fig 2: Circuit Diagram

IV. Working Principle

The working principle of the staircase cleaning robot is based on the combined operation of movement and cleaning using a simplified mechanism. When the robot is switched ON through a mobile application, the controller (such as an ESP32) sends signals to the DC gear motors. These motors drive the wheels, allowing the robot to move forward, backward, and climb stairs step by step with proper balance and stability.

For cleaning, a rotating brush is directly connected to a motor like a servo motor. As the motor rotates, the brush also rotates and sweeps dust, dirt, and small particles from the surface of each step. Since the brush is driven using an existing motor, the system becomes more compact and efficient. The rotation of the brush is continuous while the robot is in motion, ensuring that each stair is cleaned as the robot climbs or descends.

Overall, the robot works by synchronizing its movement with the brushing action. As it moves from one step to another, the rotating brush cleans the surface simultaneously. This design reduces complexity, lowers power consumption, and improves reliability while still providing effective staircase cleaning.



Fig 3: Model of Staircase Cleaning Robot

V. Observations

The observation table given below has the value of time when different operations are performed for single step.

Table 2: Table for Operation with Time

Sr.no	Operation	Time (sec)
1.	Climbing	7
2.	Clean (L-R)	2

3.	Clean (R-L)	2
4.	Cleaning	12

This table gives information about climbing and cleaning operation and their respected time is given. For climbing, up the stairs the robot takes 7 sec. For cleaning, from left to right it takes 2 sec and to clean from right to left it takes 2 sec. For cleaning, total time taken is 12 sec as the brush moves 3 times in left to right and right to left direction.

VI. Result

The staircase cleaning robot was successfully developed and tested for basic movement and cleaning operations. The robot was able to climb stairs step by step with stable motion using its wheel mechanism, while the rotating brush effectively removed dust and small particles from the surface of each step. The control through a mobile application worked properly, allowing smooth operation and direction control. The overall performance showed that the robot can handle simple staircase conditions and perform cleaning simultaneously, with satisfactory efficiency for a prototype model.

VII. Conclusion

It can be observed that a simple and cost-effective staircase cleaning robot can be designed using easily available components and basic control systems. The integration of movement and cleaning functions in a single system reduces manual effort and improves safety while cleaning stairs. Although there are some limitations in terms of cleaning depth and adaptability to different stair types, the robot demonstrates a practical approach toward automated staircase cleaning. With further improvements in design, sensing, and efficiency, this system has good potential for real-world applications.

VIII. Future Scope

The future scope of the staircase cleaning robot focuses on improving its movement, stability, and cleaning efficiency. Future designs can include better grip and adaptive mechanisms to handle uneven or slippery stairs more effectively. The cleaning system can also be enhanced to remove fine dust and stubborn dirt more efficiently. In addition, integrating smart sensors for obstacle detection and automatic control, along with improved battery performance, can make the robot more reliable, energy-efficient, and suitable for wider real-life applications.

IX. References

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