Staircase Climbing and Cleaning Robot

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Abstract: **The design and deployment of a manually operated staircase-cleaning and climbing robot, specifically designed for effective multi-level environment maintenance, is presented in this work. For accurate motor control, the robot uses an ESP32 microprocessor to incorporate a serial servo bus and serial bus servo driver. The robot is made to easily traverse and clean staircases and is outfitted with vacuum brushes for efficient cleaning. An easy-to-use joystick interface makes control possible and allows for smooth operation for both household and business applications can benefit from the system's affordability and scalability. Functional testing is used to validate the suggested design, proving its usefulness and effectiveness.**

I. INTRODUCTION

In recent years, there has been a lot of interest in the creation of semi-autonomous and autonomous robots for use in both industrial and home settings. The design and development of a robot that climbs and cleans stairs using a joystick interface is shown in this work. For accurate motor control and communication, the robot incorporates cutting-edge parts such an ESP32 microprocessor, a serial servo bus, and a serial bus servo driver. Furthermore, it has vacuum brushes for effective cleaning of stairs and flat surfaces. Because of the joystick control's user-friendly functioning, it may be used in a variety of settings. The goal of this research is to contribute to the expanding field of robotic automation by addressing the difficulties associated with cleaning and navigating staircases. For both residential and commercial cleaning applications, the suggested method offers an affordable and useful option.

II. SYSTEM ARCHITECTURE AND DESIGN

1. Mechanical Design: The robot's sturdy, small frame is made to be mobile and capable of climbing stairs. Its omnidirectional movement, made possible by meccanum wheels, allows for seamless surface transitions and accurate navigation in confined places. The robot can securely lift objects and climb stairs thanks to the integration of a serial servo motor that modifies its stance. Extra stability is offered by a castor wheel, particularly on uneven surfaces like steps. The chassis is made to support cleaning equipment (such as brushes or suction systems) while remaining balanced while in use.

2. Electrical Design: The ESP32 microprocessor controls power systems, motor drivers, and sensors as the main control unit. The meccanum wheels and servo motor are controlled by motor drivers, while obstacle detection and navigation are made possible by sensors (such as ultrasonic and infrared). The system is powered by a Li-ion battery, and energy efficiency during cleaning and stair climbing is ensured by a power management module.

3. Control System: The robot is operated manually through a smartphone app that connects to the ESP32 via Wi-Fi or Bluetooth. Through the app's user-friendly interface, users can manage the robot's movement, turn on cleaning features, and keep an eye on its condition in real time. The ESP32 interprets user inputs and synchronizes

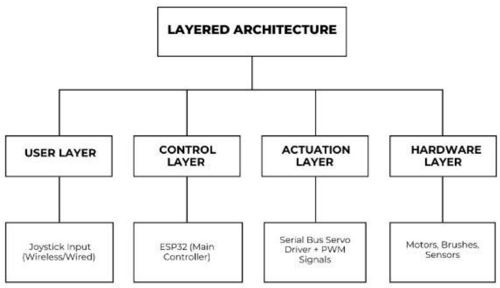

Figure 1: Software Architecture

A. ESP32 microcontroller: In which functions as the primary control unit of the stair-cleaning robot's hardware design, interfaces with a joystick for manual operation using ADC or wireless protocols (For stair-climbing kinematics, high-torque servos are connected to a serial servo bus (such as the LewanSoul LX-16A) for actuators, and the vacuum brushes and suction fan are powered by PWM-controlled DC motors. A 14.8V LiPo battery provides power, which is then controlled by buck/boost converters to drop it to 5V for logic and 12V for motors. INA219 current sensors are used to monitor the power levels.

B. Emergency stop triggers: opto-isolation for servo power, and tilt detection (MPU6050 IMU) are examples of safety features. With 3D-printed mechanical components housing electronics in a low-center-of-mass arrangement and all communication flowing through a single UART backbone for minimal wire complexity, the design places a strong emphasis on adaptability. This design guarantees durability for uneven terrain, energy efficiency, and real-time responsiveness.

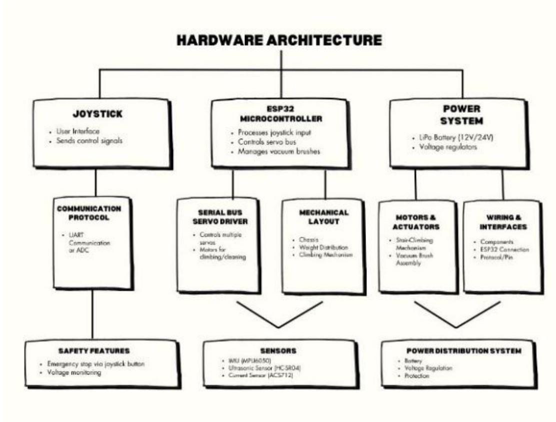

Figure 2: Hardware Architecture

C. Design: The main emphasis of Fusion 360's 3D design is a lightweight, modular chassis that is ideal for stair climbing. It includes rubber tracks with traction-enhancing 3D-printed sprockets and a front-mounted vacuum brush assembly that is tilted at a 45° angle to efficiently clean stair edges. The battery compartment is positioned low to improve stability, while the electronics bay, which is in the centre of mass, contains the ESP32 controller, servo drivers, and power regulators. Stress simulations verify the structural integrity under load, and parametric modelling guarantees changeable track tension.

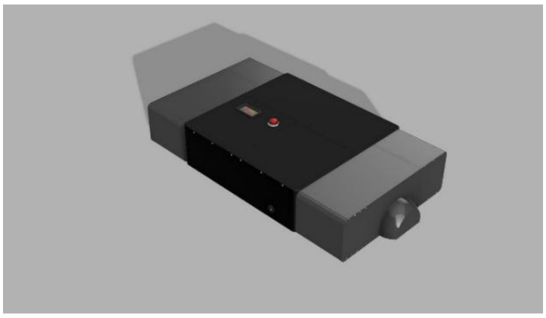

Figure 3: Design

A. POWER MANAGEMENT SYSTEM:

I. Power Budgeting:

Component	Voltage	Current (Peak)	Power Source
ESP-8266 (Controller)	5V	500mA	5V Buck
Serial Bus Servos (x2)	7.4V	2.5A each	LiPo Battery
Vacuum Brushes (x2)	12V	3A total	12VBoost
Sensors (IMU, US)	3.3V	100mA	ESP32 3.3V Regulator

B. USER INTERFACE:

I. Joystick Hardware Options:

Type	Connection	Pros	Cons
Analog	ESP32 ADC	Simple, low-cost	Limited range
Digital	I2C/SPI	Precise (e.g. ADS1115)	Complex wiring
Wireless	Bluetooth	No cables	Latency (~100ms)

II. Actuation System:

Component	Specification	Control Method
Serial Bus Servos	Lewan-Soul LX-17A (2x)	Half-duplex UART@115200
Vacuum Brush Motors	JG-37GM 12V DC + Optical Encoders	PWM@25kHz + PID Control
Suction Fan	12V Blower (2A)	MOSFET Switch

III. STAIR-CLIMBING MECHANISM

A serial servo motor is used in the stair-climbing mechanism to change the robot's posture, allowing it to raise its front or back portion to match the stair steps. The robot moves in a series of steps: the meccanum wheels propel it ahead, the servo motor tilts the chassis forward to raise the front wheels onto the first step, and the robot approaches the stairs. For every step, this procedure is repeated, with the castor wheel offering stability throughout changes. Maintaining stability and balance on uneven surfaces, making sure servo control is accurate to prevent tipping, and controlling power consumption during the energy-intensive climbing process are some of the primary problems. To carry cleaning mechanisms and securely climb and descend stairs, the design places a high priority on fluid, controlled movements.

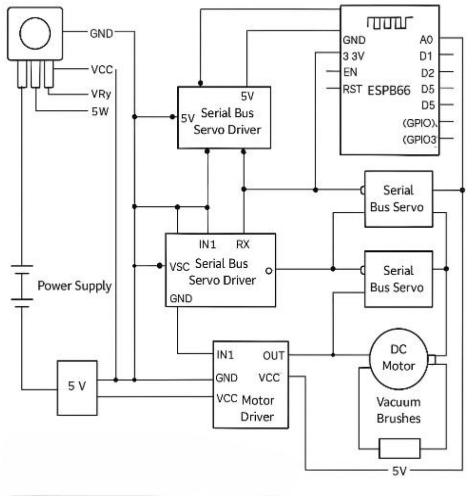

Figure 4: Schematic circuit diagram

IV. CLEANING MECHANISM

The cleaning mechanism uses parts like revolving brushes to efficiently clean surfaces of dust, debris, and stains. To ensure smooth operation when the robot travels or climbs stairs, these parts are positioned strategically underneath it. When in motion, the brushes and suction systems continue to clean continuously, and for wet cleaning jobs, the mopping mechanism can be turned on. Keeping cleaning performance consistent on uneven surfaces, like stairs, making sure cleaning components don't impede the robot's movement, and controlling power consumption to balance cleaning and mobility responsibilities are some of the issues that come with integrating cleaning functions with mobility. Effective cleaning modules that are small and light without sacrificing the robot's stability or maneuverability are the main emphasis of the design.

V. MOBILITY AND NAVIGATION

The robot can move forward, backward, sideways, and rotate in place thanks to its meccanum wheels, which improve its mobility and navigation and make it extremely maneuverable in confined places. To prevent collisions and navigate challenging environments, ultrasonic and infrared sensors are used for obstacle recognition, giving real-time data. When moving from flat surfaces to stairwells, the robot detects the stairway edge using its sensors, and the serial servo motor modifies its position to match the steps. When climbing or descending, the meccanum wheels provide you with the traction you need, and the castor wheel keeps you stable so you can move across various terrains safely and smoothly.

VI. POWER MANAGEMENT AND EFFICIENCY

For the robot's power management system to supply the energy required by its motors, sensors, and cleaning mechanisms, especially while performing power-intensive tasks like stair climbing a high-capacity Li-ion battery is essential. Low-power components, efficient motor drivers, and clever power distribution algorithms that rank jobs according to operating requirements are all used to optimize energy use. Techniques including dynamic power adjustment based on load, regenerative braking for the meccanum wheels, and sleep modes during inactivity all contribute to increased efficiency. By ensuring prolonged operation, these precautions balance performance and energy saving, enabling robots to carry out cleaning and stair-climbing chores without the need for frequent recharging.

VII. CHALLENGES AND SOLUTIONS

Maintaining stability on stairs, maximizing power efficiency, and attaining exact control are major obstacles. A sturdy chassis and castor wheel for balance, sophisticated control algorithms for seamless motor operation, and sensor integration for real-time feedback are some examples of mechanical design advancements that solve these issues.

VIII. TESTING AND RESULTS

The robot's ability to successfully climb stairs, clean effectively, and be controlled by hand via a smartphone app was demonstrated in both simulated and real-world tests conducted on flat surfaces and stairwells. Limitations include sporadic unsteadiness on steep stairs and increased power usage while climbing, indicating areas that need improvement, such larger battery capacity and improved control algorithms for greater versatility.

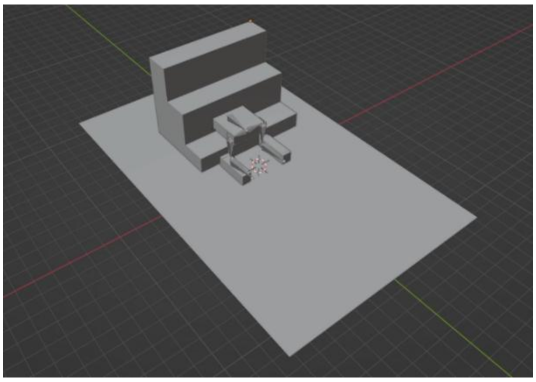

Figure 5: Simulation

IX. CALCULATION

A. Weight (Force) = 604.28 g = 0.60428 kg
Height (Distance from pivot) = 285 mm = 0.285 m
Acceleration due to gravity = 9.81 m/s²

1.Convert weight to force in Newtons:
F = 0.60428 \times 9.81 = 5.933

2. Compute torque:
T = 5.933 \times 0.285 = 1.690

B. Weight (Force) = 394.91 g = 0.39491 kg
Height (Distance from pivot) = 285 mm = 0.285 m
Acceleration due to gravity = 9.81 m/s²

1. Convert weight to force in Newtons:
F = 0.39491 \times 9.81 = 3.875

2. Compute torque:
T = 3.875 \times 0.285 = 1.105

X. CONCLUSION

This robot cleans and climbs stairs using an ESP32 with serial bus servo control and modular vacuum brushes for effective, accurate cleaning. It guarantees dependable operation thanks to LiPo batteries that have voltage management and safety features including low-voltage cutoff and emergency stop. The joystick may be used in a variety of settings since it provides both wired and wireless manual control. AI-based obstacle detection is one example of a future development that might increase autonomy and expand its uses.

XI. REFERENCE

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