

Design and Fabrication of Advance Staircase Climbing Robot

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Abstract: This paper presents the design and fabrication of an advanced staircase-climbing robot capable of traversing steps and uneven terrains with improved stability and efficiency. The objective is to overcome the limitations of conventional wheeled robots in obstacle negotiation. The proposed system employs a rocker-bogie mechanism that ensures continuous ground contact of all six wheels, enhancing traction and load distribution. A lightweight PVC chassis is used to reduce power consumption while maintaining structural strength. Each wheel is driven by a high-torque DC geared motor to generate sufficient force for stair ascent and descent. An Arduino UNO R3-based control system coordinates motor operations, with provision for future integration of autonomous navigation. Experimental evaluation demonstrates successful climbing of standard staircases with stable performance and effective load handling for light payloads such as sensors or cameras. The results indicate improved mobility and reliability in rough environments. However, performance is influenced by motor torque and battery capacity, and the absence of advanced feedback control limits precision. The system shows strong potential for applications in rescue, inspection, and surveillance tasks.

Key Words: Staircase climbing robot, Rocker-bogie mechanism, mobile robotics, terrain navigation, DC geared motors, Arduino control.

1. INTRODUCTION

In recent years, robotics has advanced significantly, enabling the development of systems capable of performing complex tasks with minimal human intervention. However, mobility over uneven terrains, particularly structured obstacles such as staircases, remains a major challenge. Conventional wheeled robots are primarily designed for flat surfaces and often fail to maintain stability, traction, and control while navigating steps. This limitation restricts their effectiveness in critical applications such as disaster rescue, multi-level surveillance, and material transport in environments lacking elevator access. Addressing this challenge requires innovative mechanical configurations and efficient control strategies.

This work focuses on the design and development of a staircase-climbing robot based on the rocker-bogie mechanism. The rocker-bogie system, a passive

suspension arrangement, ensures continuous ground contact and uniform load distribution across all wheels, thereby enhancing stability and climbing capability without the need for complex active suspension systems. The robot is constructed using a lightweight yet robust PVC chassis to achieve a balance between structural strength and energy efficiency.

The primary objective of this study is to design, fabricate, and evaluate a functional prototype capable of reliably ascending and descending standard staircases. The system integrates high-torque DC geared motors for propulsion, L298N motor drivers for actuation control, and an Arduino UNO R3 microcontroller for system coordination. The scope of the work includes mechanical design of the chassis, selection and integration of electronic components, development of control logic for synchronized motor operation, and experimental performance evaluation on staircase environments. Although the current implementation emphasizes manual control, the platform is designed to support future enhancements in sensing, automation, and intelligent navigation.

2. NEED

The need for a staircase-climbing bot arises from the limitations of conventional mobile robots in navigating uneven terrains and vertical obstacles such as stairs. In real-world scenarios like disaster rescue operations, military surveillance, industrial inspection, and assistance in multi-storey buildings without elevators, mobility across different levels is essential. Traditional wheeled robots are primarily designed for flat surfaces and often fail to maintain stability, traction, and control while climbing steps, restricting their practical usability. A robot capable of efficiently climbing stairs can significantly enhance operational effectiveness in such environments by enabling access to otherwise unreachable areas. Therefore, the development of a robust and stable staircase-climbing mechanism, such as the rocker-bogie system, becomes necessary to ensure reliable performance, improved safety, and expanded application potential in critical and everyday tasks.

3. PROBLEM STATMENT

Conventional wheeled robots are not capable of efficiently navigating staircases and uneven terrains due to limitations in stability, traction, and load distribution. This restricts their use in critical applications such as rescue operations, surveillance, and multi-level transportation. Therefore, there is a need to develop a stable, reliable, and cost-effective robotic system capable of climbing stairs and operating effectively in such environments.

4. EXPERIMENTAL SETUP

4.1 Mechanical Structure

The chassis and frame are constructed using PVC pipes, joined by PVC elbows, joints, and end caps. The structure is designed to ensure rigidity and uniform weight distribution. The motor mounts are attached to the PVC frame using metal clamps aka Jubilee Clip.



Fig 1: Rocker Bogie made from PVC

4.1 Locomotion Mechanism

The locomotion mechanism determines the robot's ability to move efficiently over uneven and elevated surfaces such as stairs. In this project, rocker-bogie mechanism is employed to achieve stable and adaptive motion. This mechanism is widely recognized for its capability to traverse rough terrains without the need for complex suspension systems or active balancing control. The rocker-bogie system consists of two main linkages on each side of the robot: the "rocker" and the "bogie."

The rocker is the primary arm connected to the main chassis, while the bogie is a secondary link attached to the rocker. Each linkage supports multiple wheels, typically arranged in such a way that the load of the robot is evenly distributed across all contact points. This configuration ensures that at least two or more wheels remain in contact

with the ground or stair surface at any given time, thereby maintaining stability during motion.



Fig 2: Rocker and Bogie

When the robot approaches a staircase, the front wheel of the rocker assembly makes initial contact with the step. As the wheel begins to climb, the rocker pivots upward, allowing the subsequent wheels to follow in sequence. The bogie mechanism further assists in this process by adjusting its angle relative to the rocker, enabling the rear wheels to climb smoothly without causing abrupt shifts in the robot's center of gravity. This coordinated movement allows the robot to ascend stairs in a continuous and controlled manner.

4.3 Control and Electronic System

The control and electronic system acts as the central processing unit of the robot, enabling coordination between mechanical motion and user input. In this project, the system is built around the Arduino UNO R3 microcontroller and L298N motor drivers, which together facilitate precise control of multiple DC geared motors required for locomotion.

The Arduino UNO R3 serves as the primary control unit, executing programmed instructions and generating control signals for motor operation. It processes input commands from manual interfaces or predefined logic and converts them into output signals. These signals are transmitted in the form of digital HIGH/LOW logic and Pulse Width Modulation (PWM), enabling both directional control and speed regulation of the motors. The use of PWM ensures smooth acceleration and deceleration, which is critical for maintaining stability during stair climbing.



Fig 3: Arduino UNO R3

To drive the high-power DC motors, L298N motor drivers are utilized. These drivers operate as dual H-bridge circuits, allowing bidirectional control of motors. Since the Arduino cannot supply sufficient current directly, the L298N modules act as an interface between the low-power control signals and the high-current motor requirements. Each driver can control multiple motors, and multiple drivers can be used in parallel to support the multi-wheel configuration of the rocker-bogie system.



Fig 4: L298N Motor Driver

The control architecture is designed to ensure synchronized operation of all motors. Proper coordination is essential to maintain uniform torque distribution and prevent instability or slippage during stair climbing. The motors on each side of the robot are controlled in a coordinated manner through programmed logic in the Arduino, enabling smooth and stable movement.

A dedicated battery supply powers the entire system. The motor drivers are provided with a higher voltage suitable for driving the motors, while the Arduino operates at a regulated lower voltage (typically derived from a 9V battery or voltage regulator), ensuring safe and efficient operation of the control circuitry.

5. SOLIDWORKS OVERVIEW

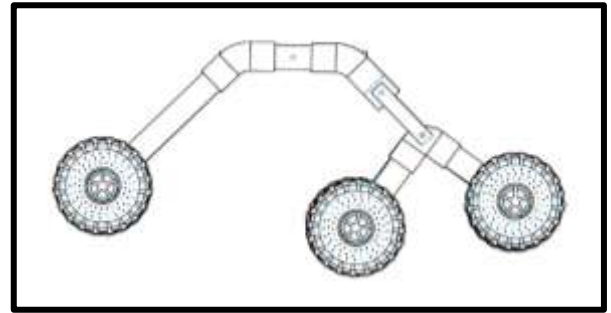


Fig 5: Side View of the Structure

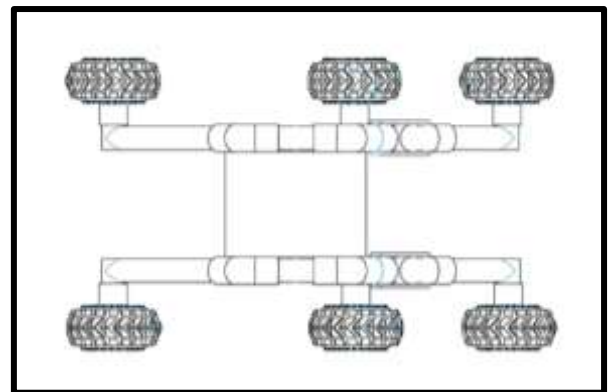
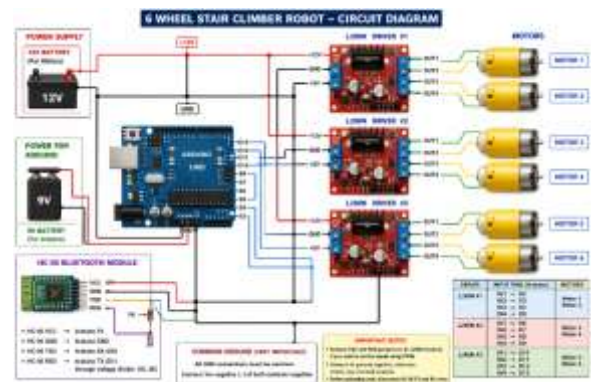


Fig 6: Top View of the Structure

The CAD model illustrates the mechanical configuration of the robot, including the PVC frame structure, rocker-bogie mechanism, wheel assembly. The design was developed to optimize balance, stability, and weight distribution for effective stair-climbing performance. The SolidWorks drawing includes multiple orthographic and isometric views that provide a comprehensive understanding of the robot's geometry and dimensions. This model served as the foundation for fabrication planning, component alignment, and dimensional verification during the design phase.

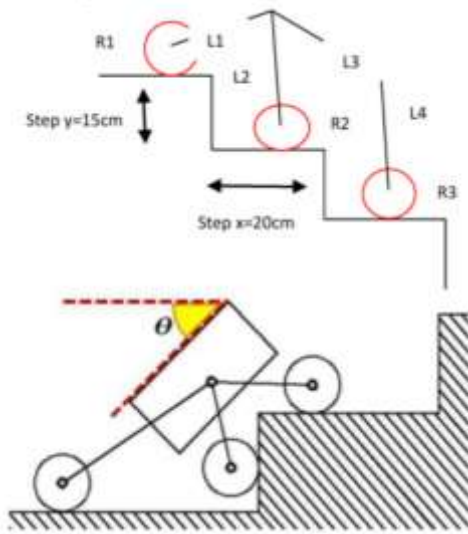
6. CIRCUIT DIAGRAM

Fig 7: Circuit Diagram



7. CALCULATIONS

Tilt Angle



$$\theta = \tan^{-1} \frac{y}{x}$$

$$\theta = \tan^{-1} \frac{15}{20}$$

$$\theta = 36.86^\circ$$

$$\text{Tilt angle } (\theta) = 36.86^\circ$$

Rocker Arm Specifications

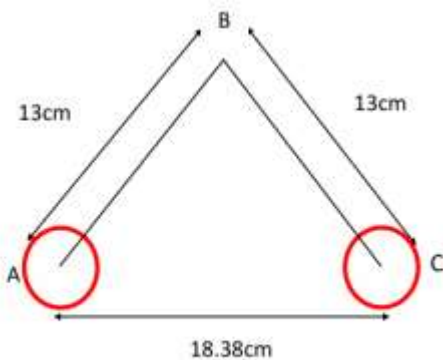


Fig-2: Rocker Arm

Centre to center distance between two front tires

By Pythagoras theorem,

$$AC = \sqrt{AB^2 + BC^2}$$

$$AC = \sqrt{13^2 + 13^2}$$

$$AC = 18.38 \text{ cm}$$

$$\text{Length CD} = \text{Length AC} + \text{Length AD}$$

$$= 18.38 + 27$$

$$= 45.38 \text{ cm}$$

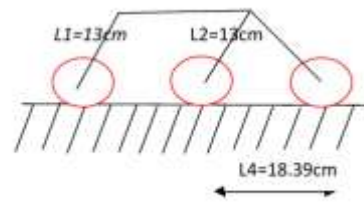


Fig-3

$$L1 + L2 > L4 \quad \dots L1 = L2 = \text{length of rocker arm}$$

$$L2 + L4 > L1 \quad \dots L4 = \text{distance between rocker arm } L4 + L1 > L1$$

$$r1 = \text{radius of front wheel of rocker} \quad r2 =$$

$$\text{radius of rear wheel of rocker}$$

$$L4 > r1 + r2$$

$$L3 - r3 > L2 + r2$$

$$L4 = 18.39 \text{ cm}$$

8. CODING

char command;

// Motor driver pins

```
int motors[12] = {
    2,3,4,5,    // Driver 1
    6,7,8,9,    // Driver 2
    10,11,12,13 // Driver 3
};
```

```
void setup() {
    Serial.begin(9600);
```

```
    for(int i=0; i<12; i++){
        pinMode(motors[i], OUTPUT);
    }
}
```

```
void loop() {
    if(Serial.available()){
        command = Serial.read();
```

```
        switch(command){
```

```
            case 'F': forward(); break;
            case 'B': backward(); break;
            case 'L': left(); break;
            case 'R': right(); break;
            case 'S': stopAll(); break;
```

```
        }
    }
}
```

// ===== FUNCTIONS =====

```
void forward(){
    for(int i=0; i<12; i+=2){
        digitalWrite(motors[i], HIGH);
        digitalWrite(motors[i+1], LOW);
    }
}

void backward(){
    for(int i=0; i<12; i+=2){
        digitalWrite(motors[i], LOW);
        digitalWrite(motors[i+1], HIGH);
    }
}

void left(){
    for(int i=0; i<12; i+=4){
        // Left motors backward
        digitalWrite(motors[i], LOW);
        digitalWrite(motors[i+1], HIGH);

        // Right motors forward
        digitalWrite(motors[i+2], HIGH);
        digitalWrite(motors[i+3], LOW);
    }
}

void right(){
    for(int i=0; i<12; i+=4){
        // Left motors forward
        digitalWrite(motors[i], HIGH);
        digitalWrite(motors[i+1], LOW);

        // Right motors backward
        digitalWrite(motors[i+2], LOW);
        digitalWrite(motors[i+3], HIGH);
    }
}

void stopAll(){
    for(int i=0; i<12; i++){
        digitalWrite(motors[i], LOW);
    }
}
```

9. FUTURE SCOPE

The current staircase-climbing robot demonstrates a functional and cost-effective solution for navigating staircases using a rocker-bogie mechanism. However, there are several opportunities to enhance its performance, efficiency, and application range through further development and integration of advanced technologies.

One major area of improvement is the implementation of autonomous navigation. By integrating sensors such as ultrasonic sensors, LiDAR, or depth cameras, along with advanced algorithms, the robot can be made capable of detecting stairs, avoiding obstacles, and making real-time decisions without human intervention.

Additionally, incorporating feedback systems like encoders or inertial measurement units (IMUs) would enable closed-loop control, resulting in more precise and stable movement.

The robot can also be extended for practical applications such as search and rescue operations, military reconnaissance, and assistance for physically challenged individuals. For such applications, additional features like payload handling, wireless communication, GPS integration, and real-time video transmission can be incorporated.

Finally, the integration of Internet of Things (IoT) technology can enable remote monitoring and control of the robot through mobile or web-based interfaces. This would allow the robot to be operated in hazardous or inaccessible environments, increasing its usefulness in real-world scenarios.

10. CONCLUSIONS

This project focuses on overcoming the mobility limitations of conventional robots when faced with staircases and uneven terrains. Through careful analysis and systematic planning, the design employs a rocker-bogie mechanism combined with a lightweight PVC frame to achieve both stability and cost-effectiveness. The use of PVC material ensures reduced overall weight while maintaining sufficient structural strength for climbing operations. Integration of sensors and a microcontroller-based control system allowed the robot to operate seamlessly and maintain balance during movement. Analytical evaluations on torque, load distribution, and centre of gravity confirm the technical feasibility of the design for real-world applications such as inspection, rescue operations, and surveillance in multi-level environments. Overall, the investigation establishes a strong foundation for developing terrain-adaptive mobile robots that are affordable, efficient, and reliable. The logical analysis and preliminary findings indicate that the proposed robot design can successfully negotiate staircases without compromising balance or performance. The project demonstrates that by combining a simple mechanical structure with intelligent control, a practical robotic system can be developed with limited resources.

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