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Stair Climbing Robot

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Abstract

This project presents a stair-climbing robot designed to detect and navigate stairs using an ultrasonic sensor. The robot ascends stairs by lifting its front part with motors, while the rear part follows by using the motion of the front. If an obstacle is detected, the robot automatically changes direction to avoid collisions. This design enables the robot to efficiently navigate stairs and obstacles. The principle behind the stair climbing robot is based on combination of mechanical design, control system and sensor technology to enable over uneven surfaces and inclined stairs. The objective of this project is to design and develop a stair-climbing robot that can autonomously detect stairs using an ultrasonic sensor, navigate obstacles by changing direction, and climb stairs efficiently by using a three-part lifting mechanism.

Keywords— *Stair-Climbing Robot, Ultrasonic Sensor, Obstacle Detection, Autonomous Navigation, Robotics, Control System*

Introduction

Robots are revolutionizing various industries, including healthcare, disaster management, and military operations. Their ability to automate tasks and operate in challenging environments has made them indispensable. However, navigating complex terrains, such as staircases, remains a significant challenge. Staircases are a ubiquitous feature in urban and industrial settings, yet traditional robots equipped with wheeled or tracked mechanisms struggle to ascend or descend stairs due to their inherent design limitations. These limitations restrict their application in scenarios requiring mobility across diverse surfaces.To overcome these challenges, researchers and engineers have developed stair-climbing robots that incorporate advanced mechanical designs and control algorithms. These robots are specifically designed to adapt to height variations, steeps inclines, and uneven steps while maintaining balance and functionality. By addressing these challenges, stair-climbing robots expand the operational scope of robotics, making them suitable for a wide range of applications.This project aims to design and develop a stair climbing robot that is efficient, adaptable, and cost-effective. Such a robot has immense potential in areas like rescue operations, where navigating debris and stairs is critical; assisting elderly or disabled individuals by providing mobility solutions; and performing industrial tasks in environments with uneven terrain. The proposed robot will combine innovative design and cutting-edge technology to achieve these goals.This project presents a stair-climbing robot designed to detect and navigate stairs using an ultrasonic sensor. The robot ascends stairs by lifting its front part with motors, while the rear part follows by using the motion of the front. If an obstacle is detected, the robot automatically changes direction to avoid collisions. This design enables the robot to efficiently navigate stairs and obstacles. The principle behind the stair climbing robot is based on combination of mechanical design, control system and sensor technology to enable over uneven surfaces and inclined stairs.

The aim of the stair climbing robot project is to develop a robotic system capable of efficiently and safely navigating staircases, addressing the limitations of conventional robots that struggle with vertical and uneven surfaces. This project seeks to create a versatile and adaptive solution for environments where stairs are common, such as homes, offices, hospitals, and disaster zones. By equipping the robot with appropriate mechanical design, sensors, and control algorithms, the goal is to enable it to detect, approach, and climb stairs with stability and precision.The stair climbing robot is intended to support various real-world applications, including assisting people with mobility challenges, performing automated delivery tasks in multi-story buildings, and conducting search and rescue missions in hazardous areas. The robot's ability to climb stairs enhances its operational range, making it more effective than traditional ground-based robots. This project also aims to explore and implement different locomotion mechanisms, such as tracked systems, wheeled legs, or hybrid designs, to determine the most efficient approach for stair traversal.Ultimately, the project aims to demonstrate the feasibility and practicality of stair climbing robots, contributing to the advancement of mobile robotics and opening new possibilities for service and autonomous robots in complex, real-world environments.

Objectives

The primary objective of the stair-climbing robot project is to design and develop a robotic system capable of navigating stairs efficiently and safely. This includes creating a stable and adaptable locomotion mechanism, integrating sensors for obstacle detection and surface recognition, and implementing an intelligent control system for autonomous operation. The robot should be energy-efficient, reliable, and capable of functioning in various environments. Additional objectives include testing the robot on different stair types, ensuring user safety, and exploring real-world applications such as search and rescue, elderly assistance, and industrial automation, while promoting interdisciplinary learning in robotics and engineering.

Literature Survey

J.Smith, A.brown, and M.Davis,2020 authors of the “Design of a Stair Climbing Robot” Proposed a two block robot mechanism where one block climbs, and the other block is pulled,the major drawbacks are lacked efficient control algorithms, leading to jerky movements on uneven staircases.R.Kumar and S.patel,2018 author of the “Wheeled Robot for Stair Navigation”developed a prototype with a wheel climbing mechanism and synchronized pulling of blocks,the drawback is struggled with higher stairs and required precise calibration for every staircase.
T.Lee,K.Choi,and H.Kim,2019 author of “Autonomous Climbing Robot” introduced an autonomous control system for wheel based stair climbing robots,and the drawback is the system was computationally heavy making real time implementation challenging.M.Johnson and L.Wang,2021 author of “Robus Stair Climbing Robots” focused on a durable design with two wheeled blocks to tackle stairs and irregular surfaces,and the drawback is high power consumption and bulky design limited portability and battery life.

Software Requirements

The software requirements for the stair climbing robot using Arduino are essential for controlling its movement, sensors, and overall functionality. The primary platform is the Arduino IDE, which allows users to write, compile, and upload code to the Arduino microcontroller. Various libraries such as Servo.h, AFMotor.h, and NewPing.h are used to interface with motors and sensors. Additional tools like MIT App Inventor may be used for remote control via Bluetooth. Simulation tools such as Proteus or Tinkercad assist in testing circuit designs. These software components work together to ensure efficient operation, accurate navigation, and reliable performance of the robot.

1.Arduino Uno

The Arduino Uno is one of the most popular and versatile microcontroller boards in the world, making it a top choice for both beginners and experienced makers. Designed around the ATmega328P microcontroller chip, it offers a straightforward interface for learning programming, electronics, and embedded systems. The Uno's popularity stems from its balance of power, simplicity, and affordability, as well as the vast online community and wealth of example projects, making it an ideal starting point for all kinds of hardware prototypes.Physically, the Arduino Uno is a compact board measuring approximately 68.6 mm by 53.4 mm, with a 16 MHz clock speed and operating at a stable 5 V. The ATmega328P provides 14 digital I/O pins, of which 6 can produce PWM (Pulse-Width Modulation) signals to control devices like motors and LEDs with fine-grained intensity. Additionally, the board features 6 analog inputs that allow you to read continuous signals from devices like potentiometers and light sensors. The Uno also includes a USB interface for easy programming and serial communication, allowing you to exchange data with a computer.Powering the Arduino Uno is very straightforward. You can supply 7 to 12 volts of DC power either through its barrel jack or the Vin pin. It can also be powered directly over USB for quick prototyping. Once powered, it executes user-written code that is uploaded via the Arduino IDE — a free and beginner-friendly software tool that simplifies writing, compiling, and uploading C/C++ code to the board. The IDE also contains a large collection of libraries to help with common tasks like controlling servos, reading from analog sensors, generating PWM signals, and communicating over protocols like I2C and SPI.

2.Hc05 Blutooth Module

The HC-05 Bluetooth module is one of the most widely used wireless communication devices in the electronics and robotics world. Designed to support classic Bluetooth communication, it enables devices like microcontrollers, including the Arduino Uno, to communicate wirelessly with smartphones, laptops, or other Bluetooth-enabled hardware. Its small size, ease of use, and affordability make it a popular choice for hobbyists, students, and professionals looking to add Bluetooth-based control and data transfer to their projects.
Physically, the HC-05 is a compact breakout board built around a Bluetooth 2.0 + EDR chip. It typically features a 6-pin header with pins for VCC (power), GND, TXD (transmit data), RXD (receive data), EN (enable), and STATE. The module operates on a 3.3V logic level, but most boards include an onboard regulator, allowing you to power it with 5V directly from a microcontroller like the Arduino Uno. The HC-05 also supports a simple serial interface (UART), making it straightforward to send and receive data using the standard Serial or

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SoftwareSerial libraries in the Arduino IDE.One of the HC-05's most significant advantages is its flexibility. It can be configured as a Master or a Slave device. In Slave mode, it waits for incoming connections from other Bluetooth-enabled devices like smartphones, allowing you to control a robot or send data from sensors. In Master mode, it can actively search for and connect to other Bluetooth modules — an important feature if you want two microcontrollers to exchange data without a phone or PC in the loop. Switching between these modes and setting parameters like device name, baud rate, passkey (PIN), and pairing behavior is achieved through AT commands sent via the serial interface.

Hardware Requirements

The existing stair climbing robots are primarily designed to overcome vertical obstacles like stairs, which pose significant challenges to traditional wheeled robots. These systems are widely used in search and rescue missions, military applications, and assistive technologies for the elderly or disabled. Most existing robots use either a tri-wheel mechanism, tracked system, or leg-based design to navigate stairs.Tri-wheel systems rotate around a central axis, allowing the robot to climb stairs smoothly. Tracked robots, similar to tank tread designs, provide strong grip and stability on uneven surfaces. Leg-based robots imitate human-like walking and are highly adaptive but complex and costly. These robots often incorporate sensors such as ultrasonic or infrared for obstacle detection and path planning.Existing models rely on microcontrollers like Arduino or Raspberry Pi for control. Many use DC or stepper motors for movement and may include remote control via Bluetooth or wireless modules. However, current systems face limitations like high power consumption, limited speed, difficulty in adapting to irregular stair sizes, and complex mechanical design.Despite these challenges, the existing stair climbing robots provide a strong foundation for further innovations, emphasizing improved efficiency, adaptability, and autonomy in robotic stair navigation systems. Stair climbing robots have become an important innovation in the field of robotics, particularly for applications in rescue operations, surveillance, healthcare, and autonomous delivery systems. The primary challenge they address is the limitation of traditional wheeled robots, which cannot easily traverse vertical or uneven terrains such as staircases. Existing stair climbing robots are designed to overcome these limitations by incorporating specialized mechanical structures and control systems.One of the most common designs in existing stair climbing robots is the tri-wheel mechanism. In this system, three wheels are arranged in a triangular configuration on either side of the robot, which allows it to rotate the wheels collectively and "step" up stairs. This mechanism ensures continuous ground contact and smooth transition between steps. It is simple in design and cost-effective, making it popular in educational and basic industrial applications. However, it may struggle with irregular or steep staircases.Another widely adopted system is the tracked stair climbing robot, which uses a continuous rubber or metal track, similar to those used in tanks. These robots offer excellent grip and stability and are capable of climbing a wide range of stair types, including spiral and slippery stairs. They are commonly used in military and hazardous environments, such as bomb disposal or post-disaster rescue missions. The drawback, however, is their weight, high power consumption, and sometimes bulky size, which can reduce their agility in tight spaces.

Proposed System

The proposed stair climbing robot system is designed to overcome the limitations of existing models by offering an efficient, cost-effective, and adaptable solution suitable for various real-world applications such as rescue operations, building maintenance, and personal assistance. This system is based on a tri-wheel mechanism powered by DC motors and controlled through an Arduino microcontroller, integrated with sensors for obstacle detection and decision-making.The robot will utilize a tri-wheel configuration, where three wheels are mounted on a rotating assembly on each side. This mechanism allows the robot to rotate its wheels as a unit and step over the edge of each stair, maintaining stability and contact with the ground at all times. This design improves upon traditional two-wheel models that struggle with vertical surfaces. It offers a simpler mechanical structure compared to legged robots and is more compact than tracked systems.The core control system will be built using an Arduino Uno microcontroller. It will manage motor control, sensor inputs, and decision logic. The robot will be equipped with ultrasonic sensors for stair and obstacle detection, allowing it to measure distances and adjust its movement accordingly. Additionally, a Bluetooth module may be included for wireless control via a smartphone app, enabling manual override or remote operation.To drive the wheels, DC geared motors will be used to provide the necessary torque to lift the robot up each step. The motors will be controlled using motor driver circuits such as the L298N, interfaced with the Arduino. The robot's movement logic will be programmed to analyze sensor input and determine when to rotate the tri-wheel assembly to climb or descend a stair.

The proposed system focuses on affordability, simplicity, and functionality. It avoids the high cost and complexity of legged robots and the bulkiness of tracked systems, while still providing reliable stair climbing capabilities. Additionally, it is designed with modularity in mind, allowing easy upgrades such as adding cameras, more sensors, or

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IoT capabilities in the future.In conclusion, the proposed stair climbing robot aims to deliver a practical solution that balances mechanical simplicity, intelligent control, and adaptability. With efficient hardware and Arduino-based software, it can navigate staircases in a variety of environments, making it a promising development for tasks that require mobility over uneven or vertical surfaces.

Block Daigram

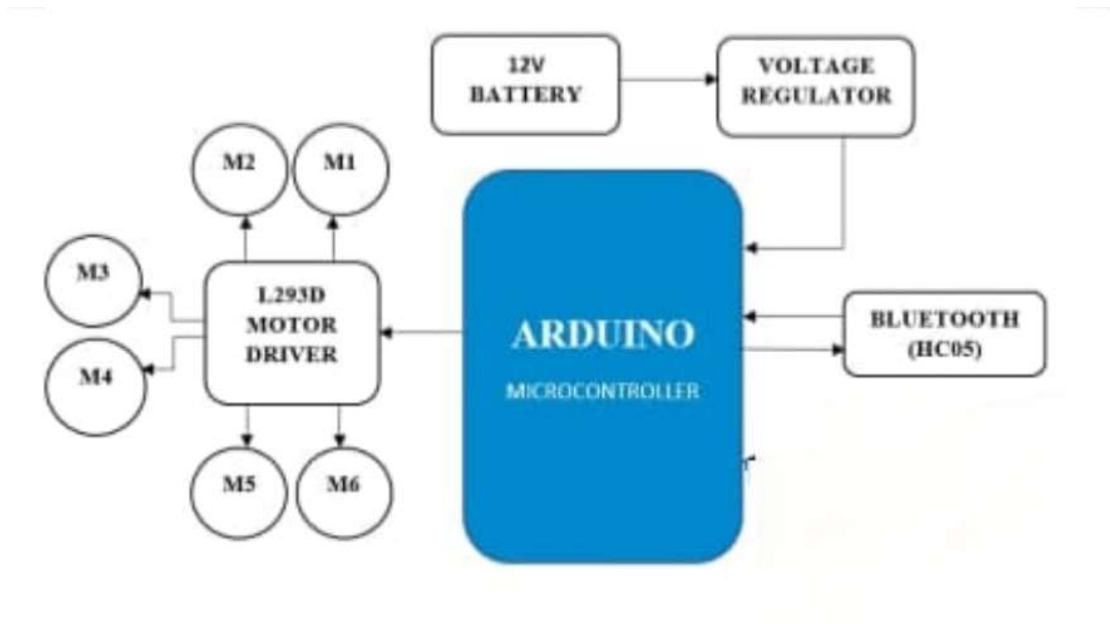

Fig Block Daigram

The block diagram illustrates the architecture of a stair climbing robot system using Arduino, showing the major components and how they interact. The system integrates power management, motor control, wireless communication, and sensor-based obstacle detection to facilitate smooth and controlled stair climbing.

1. Power Supply System:

The system is powered by a 12V battery, which provides the necessary energy for both the microcontroller and motors. Since the Arduino and some peripheral modules operate at lower voltages (typically 5V), the voltage regulator is used to step down the 12V to a stable 5V supply. This ensures that sensitive components like the Arduino board, Bluetooth module, and ultrasonic sensor are protected from overvoltage and function correctly.

2. Arduino Microcontroller:

At the core of the system is the Arduino microcontroller, which acts as the brain of the robot. It reads inputs from various sensors and communication modules and sends appropriate control signals to the motor driver to control movement. The Arduino is programmed to make decisions based on sensor inputs, such as when to move forward, climb, stop, or turn.

3. DC Motor Driver:

The L293D motor driver is responsible for controlling the motors. Since the Arduino cannot directly power motors due to limited current capacity, the motor driver acts as an interface between the Arduino and the motors. It receives control signals from the Arduino and uses external power (from the battery) to drive the motors. In this system, the motor driver controls six DC motors (M1 to M6), likely configured in a tri-wheel mechanism on each side of the robot. This configuration enables the robot to rotate and lift its wheels to climb stairs effectively

Hardware Components

The hardware components used in the “Stair Climbing Robot” are following

1.1/2 inch pipe

2.12V DC motor

3.12v Battery

4.Hc05 blutooth module

5.Connecting wires

1.1/2 inch pipe:

Fig 1 ½ inch pipe

The image shows ½ inch pipes, commonly used in plumbing and water distribution systems. These pipes are known for their high-temperature resistance, chemical durability, and corrosion-free

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nature. CPVC pipes are widely used for both hot and cold water supply in residential, commercial, and industrial applications. They are lightweight, easy to install, and require minimal maintenance. The red stripe on the pipe typically indicates suitability for hot water use.

2.12V DC Motors:

Fig 2 12V DC motor

A 12V DC motor is small and inexpensive, yet powerful enough to be used for many applications. Because choosing the right DC motor for a specific application can be challenging, it is important to work with the right company. A prime example is MET-Motors, which has been creating high-quality permanent magnet DC motors for more than 45 years. Characteristic of a 12v DC motor is the operating voltage. When a motor is powered by batteries, low operating voltages are typically preferred since fewer cells are required to obtain the specified voltage. However, at higher voltages, electronics to drive a motor are typically more efficient. Although operation is possible with volts as low as 1.5 that goes up to 100, the most common are the 6v Dc Motor, 12v DC motor, and 24v DC motor. Other key specifications of a 12v DC motor that MET-Motors can assist with include the operating current, speed, torque, and power. Although a DC motor at this voltage is ideal for many applications, the company will consider everything prior to making the final recommendation.

3.12V Battery:

Fig 3 12V Battery

The image shows an Exide Xplore VRLA motorcycle battery, a reliable power source designed for two-wheelers. This battery uses Valve Regulated Lead Acid (VRLA) technology, which is maintenance-free and spill-proof, making it ideal for rugged use. Known for its long service life and consistent performance, it delivers reliable starting power even under extreme
weather conditions. The Exide Xplore is factory-charged and ready to use, offering enhanced safety and durability due to its sealed design. It is commonly used in motorcycles and scooters, and is also suitable for small robotic and electronics projects requiring a stable 12V power supply.

4.Hc05 Bluetooth module:

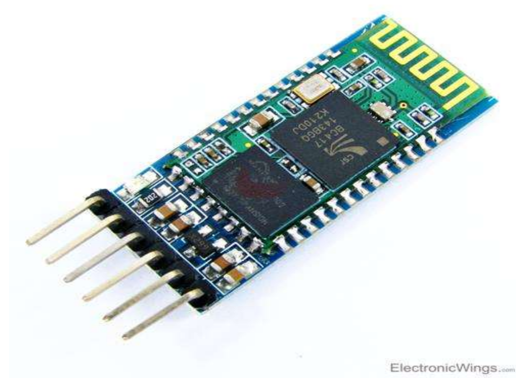

Fig 4 Hc05 Bluetooth Module

The image shows the HC-05 Bluetooth module, a popular wireless communication module used in embedded systems and Arduino projects. It allows devices to communicate wirelessly over short distances using Bluetooth Serial Communication (UART protocol). The HC-05 can operate in both master and slave modes, making it versatile for various applications such as remote control, data logging, and wireless sensor interfacing. It operates on a 3.3V logic level but is usually powered with 5V. The module features easy pairing, LED indicators, and AT command configuration. It is widely used in robotics, IoT devices, and wireless home automation projects.

5.Connecting wires:

Fig 5 Connecting Wires

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The image shows a set of jumper wires, which are essential components used in electronics and prototyping. These wires are typically used to make quick, reliable connections between components on a breadboard or between a microcontroller (like Arduino) and external devices such as sensors, LEDs, or motors. The wires come with male or female connectors at the ends, making it easy to plug them into headers or sockets. They are available in various colors to help with circuit organization and identification. Jumper wires are reusable, flexible, and ideal for DIY electronics, robotics, and educational projects involving circuit design and testing.

3.6 Circuit Daigram

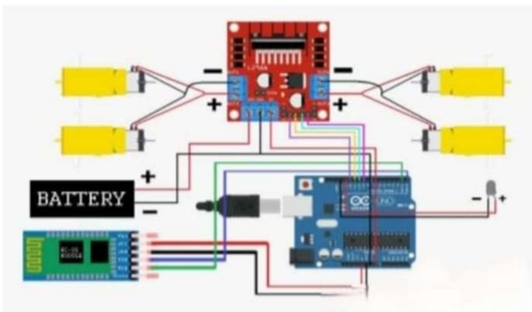

Fig 6 Circuit diagram

This circuit diagram illustrates the connection layout for a Bluetooth-controlled robotic car using an Arduino UNO, an L298N motor driver module, four DC geared motors, an HC-05
Bluetooth module, and a battery for power supply. The heart of the system is the Arduino UNO board, which acts as the microcontroller to process and execute the received commands. The four DC motors, arranged in pairs on both sides of the chassis, are connected to the L298N motor driver module. Specifically, the left pair of motors are connected to the OUT1 and OUT2 terminals, while the right pair is connected to OUT3 and OUT4. This configuration allows for independent control of each motor pair, enabling precise directional movement such as forward, backward, left, or right.The motor driver module receives power from the external battery pack, connected via the +12V and GND terminals. The 12V pin is directly linked to the battery's positive terminal, and the GND is connected to the battery's negative terminal to establish a common ground. The 5V pin of the L298N is optionally used to power the Arduino UNO if the onboard regulator is active. The Arduino board controls the motor driver via four digital output pins, which are wired to the IN1, IN2, IN3, and IN4 inputs on the L298N. These input pins receive HIGH or LOW signals from the Arduino to control the rotation direction of the motors. Additionally, the ENA and ENB enable pins of the L298N are either connected to 5V directly for full speed operation or to PWM-capable digital pins on the Arduino if speed control is required.The HC-05 Bluetooth module is connected to the Arduino for wireless communication. The VCC pin of the HC-05 is connected to the 5V output of the Arduino, and the GND pin is connected to the Arduino's ground. The TXD (transmit) pin of the HC-05 is connected to the RX (digital pin 0) of the Arduino, and the RXD (receive) pin is connected to the TX (digital pin of the Arduino, typically through a voltage divider to prevent overvoltage as the HC-05 operates at 3.3V logic. This Bluetooth module allows the robot to be controlled wirelessly using a mobile phone with a Bluetooth terminal app. Through the app, users can send characters such as 'F' for forward, 'B' for backward, 'L' for left, and 'R' for right, which are interpreted by the Arduino and translated into motor actions,and its output to an analog input pin of the Arduino for detecting obstacles or line-following. All components in the circuit share a common ground to ensure proper voltage references and stable operation. This integrated setup allows the robot to move in all directions based on Bluetooth commands while also potentially using sensors for obstacle detection or environmental interaction.

Results

we will discuss about the results of the "Stair Climbing Robot".

The stair-climbing robot successfully detects stairs and obstacles in its path using its integrated sensor system. The robot accurately identifies staircases and adapts its movement accordingly, ensuring smooth and efficient stair ascent. Additionally, the obstacle detection mechanism effectively prevents collisions by enabling real-time navigation adjustments. The robot demonstrates stable and reliable performance across various staircases, showcasing its capability to operate in dynamic environments. The implementation validates the effectiveness of the hardware and software integration, achieving the project's objectives of autonomous stair climbing and obstacle avoidance.

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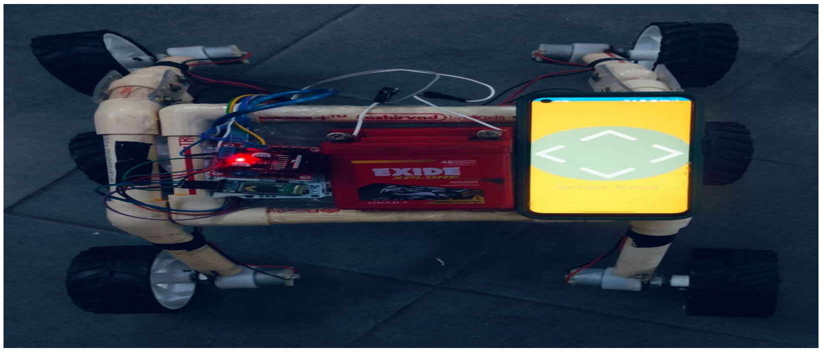

Fig 7 outcome of stair climbing robot using Arduino technology

Fig 8 Result of Stair Climbing Robot

Conclusion:

The design and development of the stair-climbing robot have been successfully implemented, demonstrating efficient stair detection, obstacle avoidance, and smooth navigation. The integration of sensors, actuators, and a robust control system has enabled the robot to adapt to different staircases and environmental conditions. The mechanical structure and locomotion design ensure stability and reliability during stair ascent. The results validate the effectiveness of the proposed system, proving its feasibility for real-world applications. Future improvements can focus on enhancing speed, optimizing power consumption, and integrating advanced AI-based navigation for increased autonomy.

Future Scope:

The development of stair-climbing robots, particularly those based on wheels, has seen significant advancements in recent years. However, there is still immense potential for future improvements to enhance their efficiency, adaptability, and versatility.

1. Improved Downward Stair Navigation:

Currently, many stair-climbing robots face challenges while descending stairs due to stability and control limitations. Future advancements can focus on:

- Adaptive Braking Mechanisms: Implementing intelligent braking systems that adjust speed and grip while moving downward.
- Self-Balancing Algorithms: Utilizing advanced control algorithms, such as PID controllers and AI-based predictive models, to maintain stability during descent.
- Enhanced Wheel Design: Developing specialized wheels with dynamic traction control to ensure smooth and safe stair descent.

2. Advanced Sensor Integration:

Future models can integrate AI-powered vision systems and sensors such as LiDAR and depth cameras to:

- Analyze stair dimensions in real-time for adaptive movement strategies.
- Predict terrain variations to adjust the robot's center of gravity dynamically.
- Enhance obstacle detection for safer navigation in complex environments.

3. Multi-Terrain Adaptability:

To make stair-climbing robots more practical, future research can focus on:

- Hybrid locomotion mechanisms combining wheels and robotic legs for seamless movement on both flat and uneven surfaces.

- Retractable wheels or robotic arms that can adapt to different stair heights and inclines.

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