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Goods Transport and Stair Climbing Robot Using Arduino UNO with Bluetooth Control

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Abstract: Staircases pose a significant mobility challenge for conventional wheeled robots, limiting their usability in multi-level environments. This paper presents the design and implementation of a cost-effective stair-climbing robot controlled via Bluetooth. The system employs a tri-wheel mechanism mounted between Y-frames, enabling rotational and climbing motion for efficient stair traversal. An Arduino UNO microcontroller, programmed in C/C++, processes wireless commands from an HC-05 Bluetooth module and drives four DC motors via relay switches. The design combines open-source embedded hardware with mechanical simplicity—eschewing complex crawler systems—while maintaining continuous ground contact and stable stair navigation. Validated through Proteus simulation and real-world testing, this scalable platform offers a reliable solution for automation, healthcare, disaster response, and assistive robotics. Its modular architecture also allows easy integration of additional sensors and control modalities to meet evolving application needs. Validated through simulation and physical testing, the robot offers a reliable, scalable platform for deployment in terrain-challenged environments.

Keywords: Stair-climbing Robot; Arduino UNO; Tri-wheel mechanism; Bluetooth control; Relay-based motor drive; Y-frame chassis; Embedded systems.

I. LITERATURE SURVEY

Stair-climbing robots have been the focus of extensive research due to their utility in navigating complex, multi-level environments where traditional wheeled platforms fail. Various methods have been explored, including tracked mechanisms, articulated legs, and wheel-based systems with passive or active step negotiation. Among these, tri-wheel designs have shown promise due to their mechanical simplicity, reduced power consumption, and reliable stair traversal without requiring high-end sensors or actuators.

Nan Li et al. [1] proposed a transformable tracked robot capable of stair navigation using online control algorithms, while Ben-Tzvi et al. [2] demonstrated autonomous stair climbing using reconfigurable tracked modules. Although effective, these systems involve complex mechanical and control architectures, making them costly and less accessible for compact or budget-limited implementations.

In contrast, simpler designs have emerged using embedded microcontrollers for control and communication. Basil Hamed [5] developed a stair-climbing robot for rescue applications using microcontroller logic and DC motor control. Similarly, DTMF-based mobile-controlled robots [3][4] introduced wireless operation but lacked autonomy and adaptability for stair navigation.

Recent implementations utilizing Arduino-based systems emphasize low cost and ease of development. Relay-controlled actuation, as an alternative to motor driver ICs, provides direct switching for DC motors with fewer components and better current-handling capabilities. Although not as commonly adopted in mobile robotics due to switching speed limitations, relays are advantageous in simple, robust climbing systems where speed and fine-tuned control are secondary to torque and reliability.

Bluetooth modules, particularly the HC-05, are widely used in robotic control due to their ease of integration and compatibility with mobile apps. When paired with Arduino UNO and a simple relay matrix, they provide an efficient platform for real-time directional control in stair environments. Projects combining these technologies have been validated through simulation platforms such as Proteus and implemented using tools like Express PCB for circuit layout, proving the feasibility of low-cost wireless climbing systems.

This project builds upon these foundations by integrating a tri-wheel mechanical assembly, relay-based motor control, and Arduino-powered wireless communication to develop a functional, scalable, and accessible stair-climbing robot. It bridges the gap between advanced research platforms and simplified educational or field-deployable solutions.

II. INTRODUCTION

A. Background and Motivation

Mobility in robotics is essential for expanding operational domains, especially in homes, industries, and disaster-prone areas. One major limitation of conventional wheeled robots is their inability to ascend staircases or navigate multi-level environments, which restricts their deployment in real-world scenarios.

Introducing stair-climbing capability into such robotic platforms significantly enhances their practicality and scope of application. This project presents a tri-wheel stair-climbing robot designed to overcome vertical obstacles using a rotating wheel assembly mounted on a Y-frame. The robot is wirelessly controlled via Bluetooth, offering remote access and real-time maneuverability. At the core of the system is an Arduino UNO microcontroller, selected for its ease of programming, accessibility, and strong support ecosystem. Unlike traditional driver-based systems, the motors in this design are actuated through four independent relay circuits, each assigned to a DC motor, providing a straightforward and cost-effective means of direction control.

B. Objectives

The primary objective of this project is to design and implement a compact, Bluetooth-controlled stair-climbing robot using a tri-wheel mechanism and relay-based motor control. The robot is intended to provide smooth, balanced stair traversal through its Y-frame tri-wheel configuration, ensuring continuous traction and stability during elevation. Wireless control is facilitated via the HC-05 Bluetooth module, allowing the user to issue directional commands through a mobile application in real time. The Arduino UNO processes incoming serial data and activates the relays accordingly, directing the flow of power to the four DC motors responsible for movement. The design and hardware interfacing are further validated using Proteus simulation software and Express PCB layout tools, ensuring the system's reliability before physical deployment. By integrating simple mechanical construction with real-time embedded control, the project offers a low-cost, scalable solution for navigating staircases in environments where traditional robots are limited.

III. METHODOLOGY

A. Hardware Design

1) Tri-Wheel Mechanism

The tri-wheel mechanism serves as the core locomotion system of the robot, specifically designed to facilitate stair climbing through rotational movement. Each tri-wheel assembly features three equally spaced wheels mounted at 120° intervals around a central rotating hub. As one wheel loses ground contact while encountering a riser, the hub rotates, bringing the next wheel into position to maintain traction and vertical lift. The tri-wheel is mounted on a Y-shaped aluminum frame, chosen for its lightweight nature and structural integrity. This passive climbing mechanism requires no active suspension, minimizing the need for additional actuators or sensors. The design is dimensioned to climb stair risers ranging from 6 to 8 inches in height and provides a balanced distribution of load to reduce slippage and improve climbing consistency.

2) Microcontroller (PIC16F72)

The Arduino UNO serves as the central control unit of the robot, handling wireless communication, command interpretation, and motor control logic. Operating at 16 MHz and powered by an ATmega328P microcontroller, the Arduino features 14 digital I/O pins, 6 analog inputs, and integrated UART, SPI, and I2C communication protocols. Commands are received via the serial interface from a Bluetooth module and are processed within a switch-case structure in the Arduino's firmware. Each command corresponds to a specific movement instruction (e.g., forward, reverse, left, right) and controls the corresponding relays assigned to each DC motor. The Arduino is programmed using the Arduino IDE in C/C++ and supports straightforward debugging and code deployment, making it ideal for rapid prototyping and iterative testing.

3) Motor Driver Circuit

Instead of a traditional H-bridge motor driver IC, this robot employs four individual electromagnetic relays—one per motor—to control motor direction and activation. Each motor is connected to a pair of relays, allowing forward and reverse control by toggling the polarity of voltage supplied to the motor. These relays are interfaced with the Arduino UNO through transistor-based driver circuits using NPN transistors and flyback diodes to handle inductive load switching safely. When a command is received, the Arduino energizes the appropriate relay coils via digital output pins, thus completing the motor circuit path. This approach, while mechanically simpler and cost-effective, supports adequate current handling for the robot's movement and eliminates the complexity of PWM or current regulation circuitry.

4) Bluetooth Communication Module

The robot utilizes an HC-05 Bluetooth module to establish a wireless connection between the Arduino UNO and a smartphone-based controller application. The module is connected to Arduino's RX and TX pins and communicates at a baud rate of 9600. Once powered on, the module enters pairing mode and connects with a mobile device running a standard Bluetooth terminal or custom app interface. Commands, 'A', 'B', 'C', 'D', and 'E' are sent from the mobile device and received serially by the Arduino. The module is powered via the Arduino's onboard 5V rail and consumes low current, making it ideal for battery-powered applications. Its reliable connection range of up to 10 meters ensures uninterrupted control in indoor and semi-outdoor environments.

5) Power Supply Unit

The robot is powered by a 12V sealed lead-acid battery capable of delivering high current required for driving multiple DC motors and energizing the relay coils. A 7805 voltage regulator is used to step down the voltage to 5V for logic-level components, including the Arduino UNO and HC-05 Bluetooth module. To ensure noise-free operation, decoupling capacitors (100µF and 0.1µF) are placed across the regulator's input and output. A manual power switch is integrated for safe system control, and LED indicators are used for visual confirmation of power status and system readiness. Additional safety measures such as reverse polarity protection diodes and polyfuses are implemented to prevent damage during voltage surges or incorrect wiring.

B. Software Architecture

1) Motion Control Firmware

The firmware for the Arduino UNO was developed using the Arduino IDE in C/C++. It follows a command-response loop structure, where the microcontroller continuously monitors the UART interface for incoming Bluetooth data. Upon receiving a character through the HC-05 module, the Arduino compares it against a predefined set of motion commands—specifically: Forward ('A'), Backward ('B'), Left ('C'), Right ('D'), and Stop ('E'). Each command corresponds to a relay switching pattern, executed via digitalWrite functions targeting the appropriate GPIO pins connected to the relay circuits. For example, a forward command simultaneously energizes the forward relays of all motors, while a turn left command actuates only the right-side relays. The firmware includes debouncing and buffer-flushing logic to avoid multiple triggers from noise or repeated inputs. While it operates in a polling loop for simplicity, the system is structured to accommodate interrupt-based enhancements if future scaling is required.

2) Simulation and Testing (Proteus)

Prior to hardware implementation, the complete system—including the Arduino UNO, HC-05 Bluetooth module, relay switching logic, and motor representation—was simulated in Proteus Design Suite. Virtual terminal blocks were used to emulate serial Bluetooth input, and LED blocks represented motor activation outputs for visual validation. The simulation helped confirm the correct logic execution for each command and ensured that digital pins toggled in sync with intended relay behavior. Timing analysis during testing confirmed that motion commands were executed with a latency of less than 150ms, providing adequate responsiveness for remote control. The simulation environment also allowed stress testing by rapidly cycling through command sequences to ensure software stability and input reliability.

IV. IMPLEMENTATION

A. Microcontroller Initialization and Command Handling

The Arduino UNO functions as the central processing unit of the robot, interpreting user commands and executing movement through relay control. Upon startup, the Arduino initializes its digital I/O pins, UART communication interface, and any necessary serial buffers. The Serial interface is configured at a baud rate of 9600 to ensure stable communication with the HC-05 Bluetooth module. The program operates on a loop that continuously checks for serial input. When a character command such as 'A', 'B', 'C', 'D', or 'E' is received, it is matched against a predefined set of conditions using a switch-case logic structure. Each matched command triggers a specific set of digital output pins, activating the corresponding relays to control motor direction. This architecture provides real-time responsiveness with low latency, ensuring accurate movement execution with minimal delay.

B. Directional Control via Relay

Instead of a motor driver IC, the robot uses four individual relays—each paired with a DC motor—to manage directional control. The Arduino sends HIGH or LOW signals to these relays through connected GPIO pins, which are routed through transistor switches for current amplification and protection. For forward movement, the relays connected to both left and right motors are activated in a way that supplies positive voltage to the motors. For reverse movement, the polarity is reversed by switching the relay combination. Left and right turns are achieved by selectively powering one side's motors while the other side remains off or is powered in the opposite direction. Stop commands deactivate all relay signals, immediately cutting motor power. This method of control simplifies hardware requirements and allows for reliable switching with adequate current handling for small to medium-load motors.

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C. Bluetooth-Based Remote Operation

Remote control of the robot is achieved using an HC-05 Bluetooth module connected to the Arduino's TX/RX pins. After pairing with a mobile device through a Bluetooth terminal application, the module receives directional commands in ASCII format and relays them to the Arduino's serial buffer. The communication range is approximately 10 meters in open areas, and typical response time is under 150 ms, providing real-time responsiveness during operation. LED indicators on the HC-05 module display connection status, ensuring the user can verify pairing and activity. Due to its low power consumption, the module is ideal for continuous operation without placing heavy demand on the onboard power supply, enabling reliable control without physical tethering.

D. Mechanical Integration and Tri-Wheel Assembly

The mechanical system of the robot is built around a Y-shaped aluminum frame equipped with two tri-wheel modules. Each tri-wheel consists of three evenly spaced wheels mounted at 120-degree intervals, enabling sequential rotation to step over stair edges. These tri-wheels are directly mounted onto the shafts of four DC motors using reinforced couplers to ensure rotational alignment and torque consistency. The structural design promotes equal weight distribution, enhancing balance and reducing the risk of tilting during vertical movement. High-friction rubber coatings on the wheels provide grip on a variety of stair surfaces, while the frame's dimensions are tailored to standard stair heights (approximately 7 inches), eliminating the need for active alignment mechanisms.

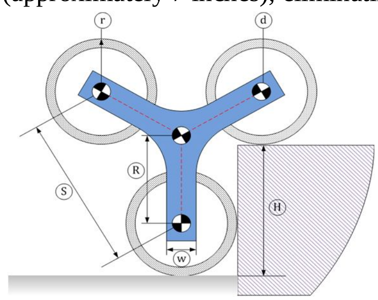

Fig.1: Tri-Wheel Mechanism

E. Final Assembly and System Integration

Once all subsystems were individually validated, the full robot was assembled on a custom-designed chassis. The Arduino UNO, Bluetooth module, and relay control board were securely mounted on the main platform using screws and insulated standoffs. All wiring was routed using labeled connectors for ease of debugging and safe maintenance. The 12V lead-acid battery was centrally positioned to maintain balance during stair climbing. After final assembly, the system underwent complete testing including wireless command reception, relay activation accuracy, motor response validation, and real-time stair climbing trials on a variety of surfaces. The robot performed reliably, executing precise movements and demonstrating successful climbing and descent on standard staircases. The integration validated that the mechanical, electrical, and firmware systems worked harmoniously, achieving the project's goal of creating a fully functional stair-climbing robot.

V. BLOCK DIAGRAM

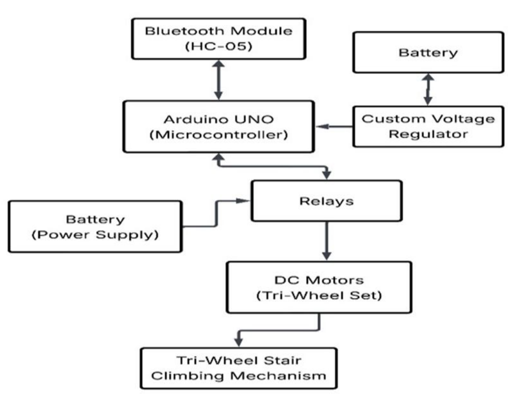

Fig.2: Block Diagram

VI. WORKING

The working of the stair-climbing robot is centered around real-time wireless control, relay-driven motor actuation, and mechanical stability through the tri-wheel assembly. Upon powering on the system using the 12V battery, the onboard voltage regulator steps down the supply to 5V for logic-level components such as the Arduino UNO and Bluetooth module. The HC-05 module automatically enters pairing mode and waits for a connection from a mobile device running a Bluetooth terminal or controller app.

Once paired, the user sends directional commands—such as 'F' for forward, 'B' for backward, 'L' for left, 'R' for right, and 'S' for stop—through the mobile interface. These commands are received over UART by the Arduino UNO, which processes the input using a switch-case logic structure. Each command triggers a specific combination of digital outputs, energizing the respective relay coils connected to the four DC motors.

The relays act as electronic switches, supplying or reversing polarity from the battery to each motor, effectively enabling directional control. When powered, the motors drive the tri-wheel mechanism, allowing the robot to roll forward, rotate, or lift itself over stairs. The tri-wheel configuration rotates step-by-step to "walk" the robot up or down risers while maintaining traction and balance.

During operation, the robot's real-time behaviour can be fully monitored and controlled by the user via the Bluetooth interface. The system responds within 100–150 ms, offering smooth navigation. The mechanical frame ensures that each step is handled with minimal shock and slippage, and the power supply supports sufficient current delivery to handle the load during climbing. The robot can traverse standard stairs (6–8 inch risers) efficiently, proving effective in terrain-challenged and multi-level environments.

VII. APPLICATIONS AND FUTURE SCOPE

The developed stair-climbing robot presents significant potential for real-world deployment in areas where traditional wheeled platforms are limited by vertical mobility challenges. Its tri-wheel mechanism, driven by relay-controlled DC motors and wirelessly operated via Bluetooth, enables stable and efficient stair traversal across various surface types. This makes the system especially valuable for rescue operations in disaster-struck areas, where stair navigation is critical for delivering supplies or reaching victims in multi-level environments. In industrial and warehouse automation, the robot can assist in transporting goods between floors without the need for elevator systems, reducing manual labor and improving operational efficiency. It also offers promising applications in home automation, particularly in supporting the elderly or individuals with mobility impairments by facilitating object transport across staircases. With its simple, low-cost design based on the Arduino UNO, the system is equally well-suited for educational demonstrations and entry-level robotics research.

Looking ahead, future enhancements could include the addition of ultrasonic sensors for obstacle detection, camera modules for visual guidance, and GPS for location-aware navigation. IoT integration through Wi-Fi or GSM modules could enable remote control and diagnostics via cloud-based dashboards. Furthermore, implementing solar charging or smart energy management systems would enhance operational autonomy for extended field use. These advancements would evolve the robot into a more intelligent, semi-autonomous solution suitable for smart infrastructure, surveillance, logistics, and assistive service applications in real-world settings.

VIII. CONCLUSION

The design and successful implementation of a Bluetooth-controlled stair-climbing robot using the Arduino UNO and relay-based motor control system demonstrates the effectiveness of combining mechanical simplicity with embedded system design. The tri-wheel mechanism, integrated with a Y-frame structure, proved to be a reliable and cost-efficient solution for navigating multi-level environments without requiring complex or expensive actuation systems. By replacing traditional motor drivers with independent relay switching, the project offers a robust alternative for controlling high-current DC motors while maintaining ease of integration and hardware flexibility. The Arduino-based firmware ensured responsive real-time communication with a mobile interface, enabling intuitive directional control and smooth stair traversal. Through detailed simulation using Proteus and practical validation on physical staircases, the robot showcased consistent performance in climbing, turning, and stopping under dynamic conditions. Its modular construction and scalable logic architecture provide a strong foundation for future enhancements such as autonomous navigation, sensor-based obstacle detection, and cloud-integrated remote control. Overall, this project delivers a practical, adaptable, and accessible mobility solution for terrain-challenged environments, opening new opportunities for applications in assistive robotics, smart automation, logistics, and emergency response systems.

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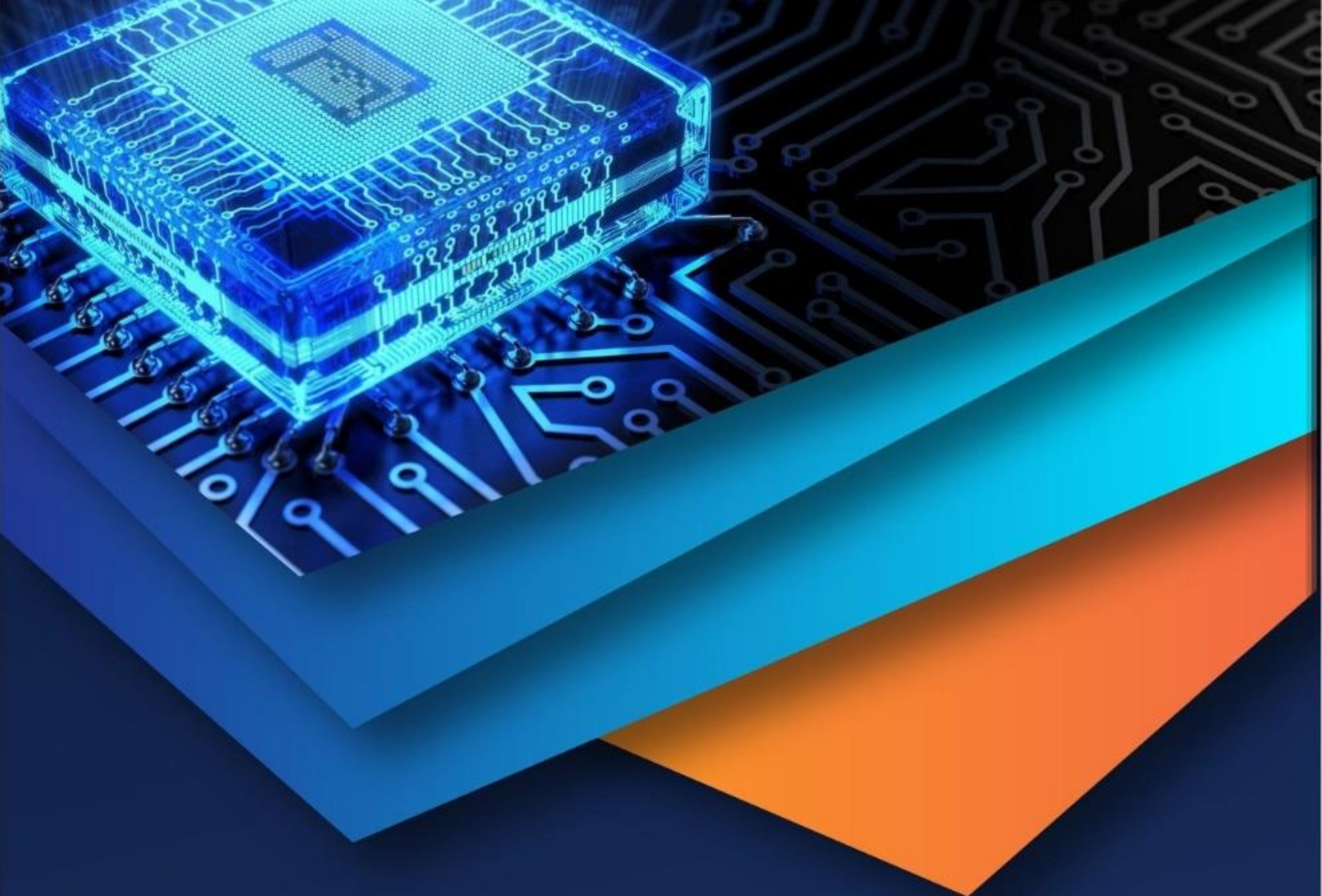

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