

# DESIGN AND DEVELOPMENT OF A STAIR CLIMBING ROBOT FOR SECURE INDOOR DELIVERY

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**Abstract:** Indoor delivery robots are becoming increasingly useful for automating routine transportation tasks in places such as hospitals, offices, laboratories, and residential buildings. Most existing indoor robots, however, are limited to flat surfaces and cannot operate effectively in multi-storey environments where staircases are common. Stair climbing presents several challenges, including maintaining balance, ensuring sufficient traction, and providing adequate motor torque for safe movement. Along with mobility, secure handling of delivered items is an important requirement, especially when sensitive or valuable materials are involved. This paper describes the design and development of a stair climbing robot intended for secure indoor delivery applications. The proposed system uses a mechanically stable structure driven by high-torque motors to achieve controlled stair navigation. Wireless control is employed for smooth operation, and an authentication mechanism is integrated to restrict unauthorized access to the delivery compartment. Experimental observations show that the developed prototype is capable of stable stair climbing and reliable operation, making it suitable for secure delivery in multi-floor indoor environments.

**IndexTerms** - stair climbing robot, secure indoor delivery, high torque motor drive, wireless robot control, authentication based access, indoor robotic system.

## I. INTRODUCTION

Indoor delivery robots are increasingly being adopted to automate routine transportation tasks in environments such as hospitals, offices, laboratories, and residential buildings. These robotic systems help reduce human effort, improve operational efficiency, and ensure consistent performance in repetitive delivery operations. With the rapid advancement of robotics and embedded systems, indoor mobile robots have become an important solution for material handling within enclosed environments. Despite their advantages, most existing indoor delivery robots are designed to operate only on flat and smooth surfaces. This limitation significantly restricts their applicability in multi-storey buildings, where staircases are a common architectural feature. Dependence on elevators or human assistance reduces the autonomy of such systems and may lead to delays in time-critical delivery tasks. Stair climbing introduces several technical challenges, including maintaining balance, ensuring sufficient traction, meeting high torque requirements, and achieving stable motion during ascent and descent.

In addition to mobility challenges, security is a crucial concern in indoor delivery applications. Robots may be required to transport sensitive or valuable items such as medical supplies, confidential documents, or electronic components. Without proper access control, there is a risk of unauthorized access, loss, or misuse of delivered items. Therefore, incorporating secure authentication mechanisms into delivery robots is essential to ensure safe and reliable operation. Another important requirement for indoor robotic systems is effective control and monitoring. During stair navigation, the likelihood of slipping or instability is higher compared to flat-surface movement. Wireless control and real-time monitoring allow operators to supervise robot movement and intervene when necessary, thereby improving operational safety and system reliability. Considering these challenges, this paper presents the design and development of a stair-climbing robot intended for secure indoor delivery applications. The proposed system focuses on achieving stable stair navigation using a mechanically robust structure driven by high-torque motors. Wireless control is implemented to enable smooth operation, and an authentication-based access mechanism is integrated to ensure secure delivery. The developed prototype aims to provide a practical and cost-effective solution for reliable indoor delivery in multi-floor environments.

## II. LITERATURE REVIEW

1. Indoor mobile robots have been widely researched for material transportation and service applications in structured environments such as hospitals, offices, and laboratories. Early indoor delivery robots mainly relied on wheeled mechanisms due to their simplicity and ease of control. These systems demonstrated reliable performance on flat and smooth surfaces; however, their operation was restricted in multi-storey buildings where staircases are common architectural features [1].

2. Several researchers identified stair navigation as a major limitation of conventional wheeled robots. Dependence on elevators or manual assistance reduces system autonomy and increases delivery time. To address this issue, various stair-climbing robotic mechanisms have been proposed, focusing on improving stability and traction during ascent and descent [2].

3. Tracked robotic mechanisms were among the earliest solutions proposed for stair climbing. These systems provide better grip and stability compared to wheels, especially on uneven surfaces. However, studies reported that tracked robots suffer from

- increased mechanical complexity, higher power consumption, and reduced manes variability on flat surfaces, which limits their practical indoor deployment [3].
4. Hybrid wheel-leg and articulated robotic systems were introduced to enhance stair-climbing capability while maintaining mobility on flat surfaces. Although these designs demonstrated effective stair navigation, they require complex mechanical structures and sophisticated control algorithms. This increases system cost and makes real-time control more challenging [4].
5. Motor torque requirements have been identified as a critical factor in stair-climbing robot design. Researchers emphasized the need for high-torque DC motors combined with appropriate gear reduction mechanisms to overcome gravitational forces during stair ascent and to ensure controlled descent. Insufficient torque has been reported as a common cause of instability and slippage in stair-climbing robots [5].
6. While most existing studies focused primarily on mechanical design and mobility enhancement, limited attention has been given to secure handling of transported items. In indoor delivery applications, robots may be required to carry sensitive or valuable materials, making security an important design consideration [6].
7. Some researchers proposed basic security mechanisms such as mechanical locks or password-based access systems for delivery robots. Although these approaches provide a basic level of protection, they may not be adequate for preventing unauthorized access in real-world indoor environments [7].
8. Wireless control and monitoring techniques have been widely adopted in indoor robotic systems to improve operational flexibility and safety. Studies showed that wireless communication allows real-time supervision and manual intervention, particularly during stair navigation where the risk of instability is higher than during flat-surface movement [8].
9. From the reviewed literature, it is observed that most indoor robotic systems address stair-climbing mobility, security, and control as separate aspects. Very few studies focus on integrating stable stair-climbing capability with secure access control and wireless operation within a single system [9].
10. The identified research gap highlights the need for an integrated stair-climbing indoor delivery robot that combines mechanical stability, high-torque motor drive, secure authentication, and wireless control to achieve reliable operation in multi-floor indoor environments [10].

### III. SYSTEM OVERVIEW

The sensing unit plays a critical role in ensuring safe navigation of the robot in indoor environments. Ultrasonic sensors are used to measure distance from obstacles and detect stair edges, while infrared sensors assist in identifying stair presence and surface variations. Continuous sensing enables the robot to adjust its motion dynamically and avoid collisions during operation. Power for the system is supplied through a rechargeable battery pack, which provides sufficient energy for motors, sensors, and control circuitry. Efficient power management is considered to support extended operation during indoor delivery tasks. Voltage regulation circuits ensure stable power supply to all modules, enhancing system reliability. The control strategy of the system is designed to support both manual and autonomous operation modes. In manual mode, the user can control robot movement through a wireless interface, allowing direct supervision during stair climbing. In autonomous mode, the controller processes sensor inputs and automatically adjusts motor speed and direction to maintain balance and stability. Security is incorporated into the system through an authentication-based access mechanism integrated with the delivery compartment. This feature ensures that only authorized users can access the delivered items, making the system suitable for applications involving sensitive or valuable materials. The integration of mobility and security enhances the overall practicality of the proposed robot.

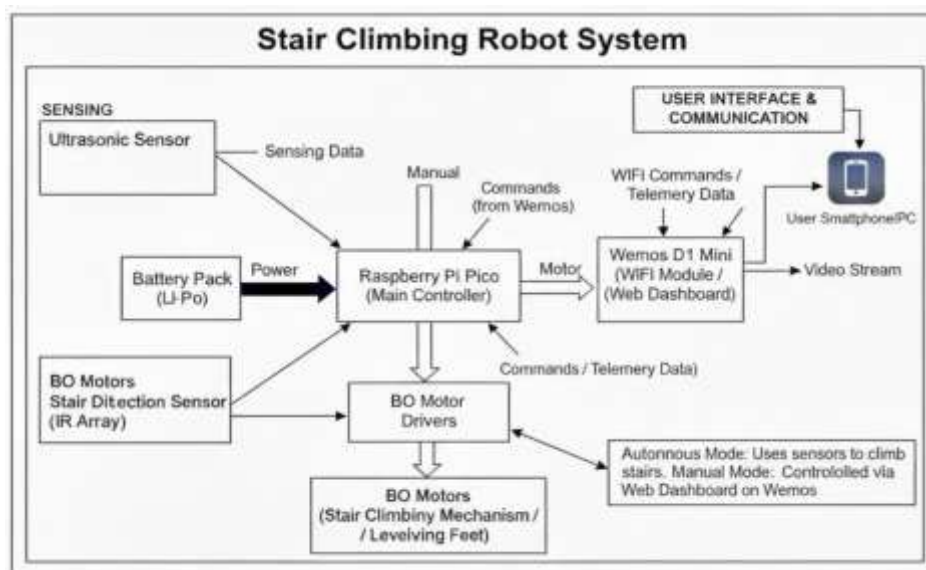


Fig. 1. Block diagram of proposed stair-climbing indoor delivery robot

The sensing unit includes ultrasonic and infrared sensors that are used to detect obstacles, stairs, and surface variations during robot movement. These sensors continuously collect environmental data and provide feedback to the main controller for real-time

decision-making. The main controller acts as the core processing unit of the system. It receives sensor inputs, processes control commands, and generates appropriate signals for motor control. The controller coordinates the operation of all system components to ensure stable stair ascent, descent, and smooth movement on flat surfaces.

High-torque DC motors driven through motor driver circuits provide the necessary torque required for stair climbing. The motor driver unit amplifies control signals from the controller and enables precise control of motor speed and direction, ensuring stable and controlled motion under load conditions.

Wireless communication enables remote control, monitoring, and user interaction through a smartphone or computer interface. This allows the operator to supervise robot operation, switch between control modes, and receive telemetry information during indoor delivery tasks. The integrated system architecture ensures coordinated operation of sensing, control, and actuation modules for reliable stair-climbing indoor delivery.

#### IV. HARDWARE DESIGN

The hardware architecture of the proposed stair-climbing robot is designed to ensure mechanical stability, reliable sensing, efficient control, and secure delivery operation. The system consists of a main controller, sensing units, motor drive circuitry, actuation mechanisms, power supply, and communication modules. Each component is selected to support stable stair navigation and controlled indoor delivery.

The Raspberry Pi Pico is used as the main controller of the system. It is responsible for processing sensor data, executing control algorithms, and generating control signals for motor operation. The controller receives inputs from the sensing units and accordingly regulates motor speed and direction using pulse width modulation signals. Its compact size, low power consumption, and adequate processing capability make it suitable for embedded robotic applications. For environmental perception and stair detection, the robot employs an ultrasonic sensor and an infrared-based stair detection sensor. The ultrasonic sensor continuously measures the distance to nearby obstacles, enabling safe navigation in indoor environments. The infrared sensor assists in detecting stair edges and elevation changes, which is critical for maintaining balance and preventing falls during stair ascent and descent. The actuation system consists of high-torque DC motors that provide sufficient force to move the robot and its payload on inclined surfaces. These motors are interfaced with the controller through a motor driver module, which allows precise control of motor speed and direction. Controlled torque ramping ensures smooth motion and reduces mechanical stress during stair-climbing operations.

The mechanical structure of the robot is designed to provide stability while climbing stairs. It incorporates a wheel-based stair-climbing mechanism that helps distribute the load evenly and maintain balance. The delivery compartment is securely mounted on the frame to protect items during movement and support secure indoor delivery.



Fig. 2. Hardware prototype of the stair-climbing indoor delivery robot

Power for the entire system is supplied using a rechargeable lithium polymer battery pack. The battery provides sufficient voltage and current to support continuous operation of the controller, sensors, motors, and communication modules. Proper voltage regulation ensures reliable performance and protects the hardware components from fluctuations.

Wireless communication is achieved using a Wi-Fi module, which enables interaction between the robot and a user interface such as a smartphone or personal computer. This allows manual control, system monitoring, and supervisory operation during stair navigation.

#### Motor Torque Requirement

The torque required for the stair-climbing operation depends on the force needed to move the robot and the radius of the wheel. The torque requirement can be expressed as:

$$T = F * r$$

Where:

- F = Force acting on the wheel (N)
- r = Radius of the wheel (m)

This relationship helps in selecting a suitable high-torque motor for stable stair-climbing operation. Relationship between Wheel Speed and Robot Velocity

The linear velocity of the robot depends on the rotational speed of the wheel and its radius. This relationship can be expressed as:

$$v = \omega * r$$

Where:

- v = Linear velocity of the robot (m/s)
- $\omega$  = Angular velocity of the wheel (rad/s)
- r = Radius of the wheel (m)

This equation helps in understanding the speed characteristics of the robot during flat surface movement and stair climbing.

## V. WORKING / METHODOLOGY

The working methodology of the proposed stair-climbing indoor delivery robot is designed to ensure safe initialization, stable navigation, secure item delivery, and controlled shutdown. The system operates through coordinated interaction between the sensing units, controller, motor drive system, wireless communication module, and security mechanism.

When the system is powered on, the controller initializes all hardware components including sensors, motor drivers, wireless communication module, and power supply unit. During this initialization stage, a self-diagnostic check is performed to verify sensor responsiveness, motor readiness, and battery status. If any abnormal condition is detected, the system enters a safe idle state to prevent unintended operation.

After successful initialization, the robot waits for commands through the wireless interface. Based on user input, the system operates either in manual mode or autonomous mode. In manual mode, movement commands such as forward motion, stair climbing, turning, and stopping are received wirelessly from the user interface. The controller processes these commands and generates appropriate motor control signals to execute the requested actions.

In autonomous mode, the robot continuously monitors data from the ultrasonic and infrared sensors. The ultrasonic sensor detects obstacles and measures distance from nearby objects, while the infrared sensor assists in identifying stair edges and elevation changes. Based on the sensor inputs, the controller determines the appropriate movement strategy and regulates motor speed and direction to maintain balance during stair ascent and descent.

Motor control logic ensures gradual variation of speed and torque to minimize sudden jerks and improve stability during stair climbing. The synchronized operation of the motors allows smooth transition between flat surface movement and stair navigation while carrying the delivery load.

Secure delivery operation is achieved through an authentication-based access mechanism. Once the robot reaches the delivery location, the authentication module verifies the authorized user. Upon successful verification, the locking mechanism is actuated to unlock the delivery compartment, allowing access to the delivered item. If authentication fails, the compartment remains locked, ensuring protection against unauthorized access.

Throughout the operation, system status and telemetry information are transmitted wirelessly to the user interface for monitoring. After completion of the delivery task or upon receiving a stop command, the robot safely halts operation and returns to an idle state.

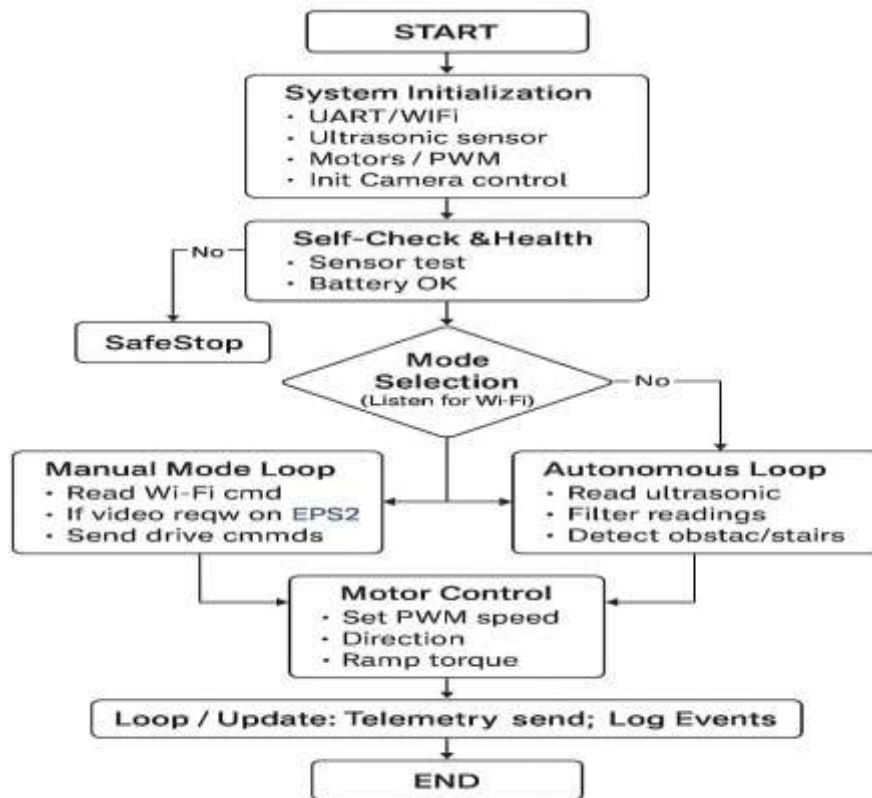


Fig. 3 Flowchart illustrating the working methodology of the proposed stair-climbing indoor delivery robot

In addition to navigation and motion control, the system incorporates a fingerprint-based authentication mechanism to ensure secure item delivery. Once the robot reaches the delivery location, the fingerprint sensor is activated and waits for authorized user input. The fingerprint data is compared with stored templates in the controller memory. If a valid match is detected, the controller energizes the solenoid lock, allowing the delivery compartment to open and the item to be accessed. In the absence of successful authentication, the solenoid remains locked, thereby preventing unauthorized access to the delivered item. This authentication mechanism enhances delivery security without affecting the core navigation and control flow of the system.

## VI. RESULTS AND DISCUSSION

The proposed stair-climbing indoor delivery robot was experimentally tested in an indoor environment to evaluate its performance in terms of stair-climbing ability, navigation stability, sensing accuracy, secure delivery operation, and real-time monitoring. The system was tested on flat surfaces and staircases under both manual and autonomous modes of operation. The results obtained from these experiments are discussed to analyse the effectiveness and reliability of the proposed system.



Fig. 4 Stair-climbing operation of the proposed indoor delivery robot

During experimental testing, the robot successfully climbed indoor staircases while maintaining balance and stability. The stair-climbing mechanism provided adequate traction, and the motor torque was sufficient to overcome gravitational forces during ascent. Smooth transition between flat surfaces and stairs was observed, confirming the effectiveness of the mechanical structure and motor control strategy.

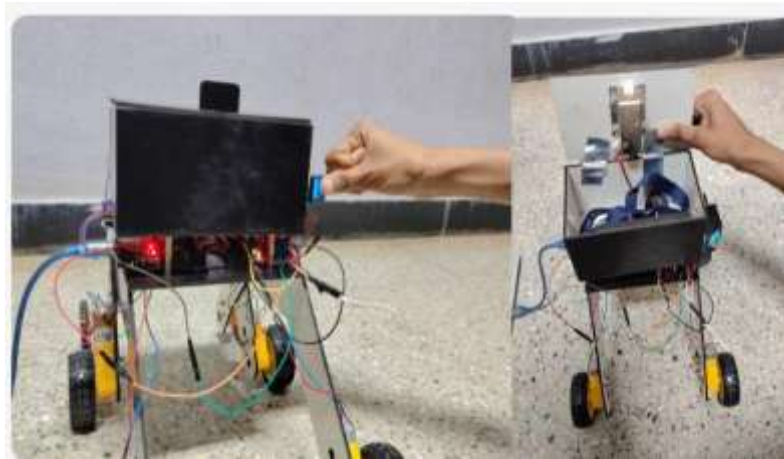


Fig. 5 Delivery operation of the stair-climbing indoor delivery robot

The delivery operation was tested in an indoor environment to evaluate secure item handling. Upon reaching the destination, the fingerprint-based authentication system verified authorized users before unlocking the delivery compartment. The solenoid lock opened only after successful authentication, while unauthorized attempts were denied. This demonstrates reliable and secure delivery operation suitable for indoor applications.

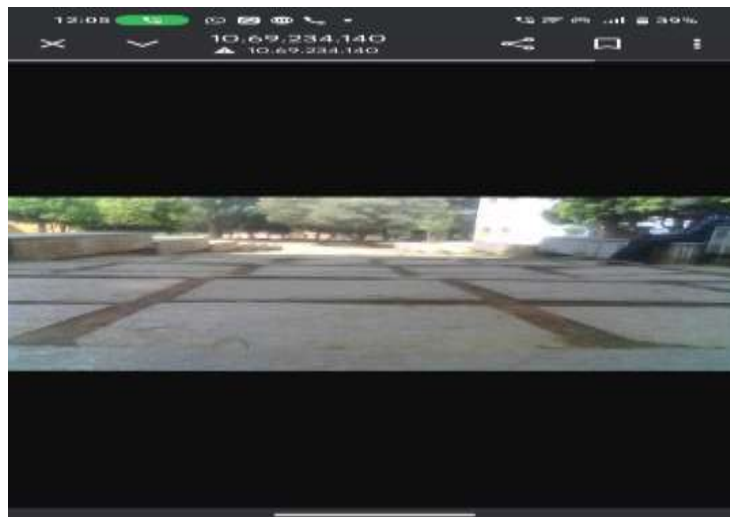


Fig. 6 Live video monitoring using ESP32 camera module

The ESP32 camera module was evaluated for real-time video monitoring during robot operation. Live video streaming enabled remote supervision of navigation and stair-climbing activities. The camera provided sufficient visual clarity for manual control and situational awareness, enhancing operational safety and user confidence during indoor delivery tasks.

Overall, the experimental results demonstrate that the proposed stair-climbing indoor delivery robot performs reliably in indoor environments. The system achieved stable stair navigation, effective obstacle detection, secure delivery through fingerprint authentication, and real-time visual monitoring using the ESP32 camera module. The integration of mobility, security, and monitoring features validates the effectiveness of the proposed design for practical indoor delivery applications. Minor limitations related to battery backup and operating range can be addressed in future enhancements.

**Table 1 Performance evaluation of the proposed stair-climbing indoor delivery robot**

Parameter	Observation
Stair-climbing capability	Successfully climbed standard indoor stairs
Stability during climbing	Stable with no major slippage observed
Obstacle detection	Accurate within indoor testing range
Delivery authentication	Successful for authorized users
Unauthorized access	Prevented by fingerprint lock
Camera monitoring	Real-time video feed available
Wireless control response	Smooth with minimal delay
Overall system performance	Reliable for indoor delivery tasks

The performance evaluation presented in Table 1 summarizes the experimental observations obtained during indoor testing of the proposed system. The results indicate reliable stair-climbing capability, stable navigation, effective obstacle detection, secure delivery through fingerprint authentication, and real-time monitoring using the ESP32 camera module. These observations confirm that the proposed robot is suitable for indoor delivery applications in multi-store environments.

## VII. CONCLUSION

The project successfully designed and implemented a stair-climbing indoor delivery robot capable of operating in multi-storey indoor environments. The proposed system integrates a stable stair-climbing mechanism, sensor-based navigation, wireless control, fingerprint-based secure delivery, and real-time monitoring using an ESP32 camera module. Experimental results demonstrated reliable stair climbing, effective obstacle detection, secure delivery operation, and smooth wireless control.

The robot was able to navigate both flat surfaces and staircases with adequate stability and minimal slippage. The fingerprint authentication mechanism ensured secure access to the delivery compartment, preventing unauthorized item retrieval. Real-time video monitoring using the ESP32 camera enhanced operational safety and allowed effective supervision during navigation and delivery tasks.

Overall, the project addresses the limitations of conventional indoor delivery robots by enabling stair navigation without external assistance. The integration of mobility, security, and monitoring features makes the proposed system suitable for applications such as hospitals, offices, and residential buildings. The results validate the feasibility and effectiveness of the stair-climbing indoor delivery robot for practical indoor use.

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