

# OmniLiftBot - An Autonomous Mecanum -Wheeled Robot for Smart Load Transport, Elevation, and Real-Time Weight Monitoring

Ms. Vaishnavi Kishor Patil, Ms. Rutuja Rajkumar Waghmare, Ms. Priyanka Ubhad,  
Mr. Ramgopal Sahu

Department of E&TC PES Modern College of Engineering  
Pune, India

**Abstract-** Material handling plays a crucial role in industrial automation, warehouse management, and logistics operations. Conventional transportation methods based on manual carts and trolleys require significant human effort, resulting in reduced operational efficiency, increased labor dependency, and limitations in confined working environments. To address these challenges, this paper presents OmniLiftBot, an autonomous Mecanum-wheeled robotic platform designed for smart load transportation, vertical load handling, and real-time payload monitoring. The proposed system is built around an ESP32 microcontroller and integrates Mecanum wheels for omnidirectional mobility, a scissor-lift mechanism for controlled elevation of loads, a load cell with HX711 module for weight measurement, and an ultrasonic sensor for obstacle detection. A Wi-Fi-based interface enables path selection and system control, allowing flexible operation in indoor environments. The combination of mobility, lifting, sensing, and monitoring functionalities within a single platform enhances the versatility of the system while reducing manual intervention. Experimental evaluation of the developed prototype demonstrates reliable navigation, effective lifting operation, accurate payload monitoring, and safe obstacle detection under controlled conditions. The proposed solution offers a compact, cost-effective, and scalable approach for modern material handling applications and can serve as a foundation for future intelligent warehouse automation systems.

**Keywords-** Autonomous Mobile Robot, Mecanum Wheel Drive, ESP32 Controller, Scissor Lift Mechanism, Load Cell Sensor.

## I. INTRODUCTION

The rapid advancement of industrial automation, smart manufacturing, and warehouse management technologies has significantly increased the demand for efficient material handling solutions. Material transportation represents one of the most fundamental operations in industrial environments, directly influencing productivity, operational efficiency, and resource utilization. Traditional material handling systems primarily rely on manual carts, trolleys, and human-operated transportation methods, which often require continuous labor involvement and are associated with limitations such as reduced efficiency, increased operational costs, and difficulties in handling materials within confined working spaces. These challenges have encouraged the development of intelligent robotic systems capable of automating transportation and handling operations while minimizing human intervention.

The emergence of Industry 4.0 has further accelerated the adoption of autonomous systems in manufacturing and logistics sectors. Modern warehouses are increasingly transitioning toward intelligent environments where transportation, storage, monitoring, and inventory management activities are performed with minimal human involvement. In such environments, robotic systems play a crucial role in ensuring continuous operation, improving workflow efficiency, and reducing dependency on manual labor. Consequently, autonomous mobile robots have gained considerable importance due to their capability to perform repetitive transportation tasks accurately and efficiently.

Initial developments in industrial robotics focused on improving the mobility and maneuverability of mobile robotic platforms operating in constrained environments. Conventional differential-drive systems provided basic locomotion capabilities; however, their movement was often limited by

turning radius constraints and restricted directional flexibility. To overcome these limitations, omnidirectional mobility systems were introduced, enabling robotic platforms to move freely in multiple directions without changing their orientation [1]. Such developments established the foundation for highly maneuverable robotic systems capable of operating efficiently in narrow industrial pathways and densely occupied workspaces.

Further advancements concentrated on the design and optimization of omnidirectional drive mechanisms. The introduction of Mecanum-wheel-based drive systems enabled robots to achieve forward, backward, lateral, diagonal, and rotational motion through coordinated wheel control [2]. Improvements in wheel construction and mechanical design further enhanced navigation accuracy and motion precision, allowing robotic systems to maintain stable movement under varying operating conditions [3]. These developments significantly expanded the applicability of omnidirectional robotic platforms in warehouse automation and logistics applications.

As robotic mobility technologies matured, research efforts increasingly focused on improving navigation intelligence and motion control capabilities. Advanced path-tracking algorithms were developed to improve trajectory-following performance and ensure accurate movement along predefined routes [4]. The integration of sensing technologies and autonomous decision-making capabilities further enhanced the operational effectiveness of mobile robots, enabling them to navigate dynamic environments while adapting to changing conditions [5]. These developments contributed significantly to the transition from manually controlled robotic platforms to autonomous mobile systems capable of performing complex transportation tasks.

The growing adoption of autonomous mobile robots in industrial applications subsequently created a demand for additional functionalities beyond simple transportation. Material handling operations frequently require not only horizontal movement but also controlled vertical positioning of loads. This requirement motivated the development of lifting mechanisms capable of performing elevation and positioning tasks while maintaining stability and structural reliability [6]. At the same time, weight monitoring technologies were incorporated into handling systems to improve payload management, operational safety, and measurement accuracy

during transportation processes [7]. The integration of these functionalities significantly enhanced the versatility of robotic platforms and expanded their range of industrial applications.

Subsequent investigations focused on improving the dynamic performance of omnidirectional robotic systems. Factors such as wheel-ground interaction, frictional effects, vibration, and mechanical stability were analyzed to improve navigation accuracy and motion smoothness [8]. Research efforts also explored lifting and handling mechanisms capable of supporting heavier payloads while maintaining compact system dimensions and structural integrity [9]. These developments contributed to the creation of robotic platforms capable of performing increasingly demanding material handling operations within industrial environments.

The continued evolution of mobile robotics further encouraged the development of highly agile and responsive robotic systems. Improvements in motion control techniques enabled more accurate velocity regulation and enhanced trajectory tracking performance [10]. Reliability also became a major area of research, resulting in the development of fault detection and monitoring methodologies capable of identifying abnormalities in wheel operation and system performance [11]. Such advancements improved operational robustness and reduced maintenance requirements, making autonomous robotic platforms more suitable for long-term industrial deployment.

Recent investigations have emphasized the application of advanced control strategies to improve navigation performance under uncertain operating conditions. Enhanced braking methodologies have been proposed to improve motion stability and vehicle safety [12]. Artificial intelligence and reinforcement learning techniques have also been introduced to optimize tracking performance and improve adaptability to dynamic environments [13]. Significant progress has been achieved in guidance control and trajectory-planning methodologies, resulting in smoother robot motion and improved path-following accuracy [14]. Furthermore, efficient predictive control algorithms have been developed to reduce computational complexity while maintaining high navigation performance [15].

Modern approaches combine intelligent sensing, advanced control algorithms, and robust mechanical architectures to achieve highly accurate and reliable operation of Mecanum-based robotic systems [16]. Continuous improvements in

trajectory tracking, disturbance rejection, and motion optimization have further enhanced system performance and operational stability [17]. In parallel, lifting technologies continue to evolve to support increasingly sophisticated material handling applications requiring precise positioning and load transportation capabilities [18].

Despite the remarkable progress achieved in autonomous transportation technologies, many existing robotic platforms continue to focus on individual functionalities such as navigation, lifting, or monitoring. The lack of integration among these subsystems often limits operational efficiency and increases system complexity. In practical warehouse environments, transportation, payload monitoring, lifting, and obstacle avoidance must operate simultaneously to achieve seamless material handling. Therefore, the development of a unified robotic platform capable of integrating all these functionalities remains an important research challenge.

Another significant limitation observed in commercially available material handling systems is their high implementation and maintenance cost. Advanced industrial robots often require sophisticated hardware, complex infrastructure, and specialized control systems, making them unsuitable for small-scale industries, educational institutions, and research laboratories. This creates a need for compact, cost-effective, and scalable robotic platforms that can provide intelligent material handling capabilities without requiring extensive investment or infrastructure modifications.

Motivated by these challenges, the proposed OmniLiftBot has been developed as an integrated autonomous material handling system capable of combining omnidirectional mobility, vertical load handling, real-time weight monitoring, obstacle detection, and wireless control within a unified platform. The system incorporates a Mecanum-wheel drive mechanism for multidirectional navigation, a scissor-lift assembly for vertical load transportation, a load-cell-based monitoring subsystem for payload measurement, and an ultrasonic sensing unit for obstacle detection. An ESP32-based control architecture coordinates the operation of all subsystems, enabling intelligent and efficient material transportation.

The proposed system aims to provide a compact, cost-effective, and scalable solution for modern warehouse automation and smart logistics applications. By integrating multiple functionalities within a single robotic platform, OmniLiftBot

seeks to reduce manual effort, improve operational flexibility, enhance transportation efficiency, and contribute toward the advancement of intelligent material handling technologies.

## II. METHODOLOGY

### A. System Architecture

The developed system is an autonomous material handling system integrating mobility, sensing, lifting, and wireless communication modules. The architecture is centered around the ESP32 microcontroller, which controls robot movement, sensor processing, lifting operation, and WiFi-based communication.

The system utilizes a Mecanum-wheel-based drive mechanism for omni-directional navigation, along with weight monitoring and obstacle detection for safe operation. A lifting mechanism is integrated for controlled load handling and elevation. The overall system architecture ensures coordinated operation of navigation, sensing, and lifting modules for efficient indoor material handling applications.

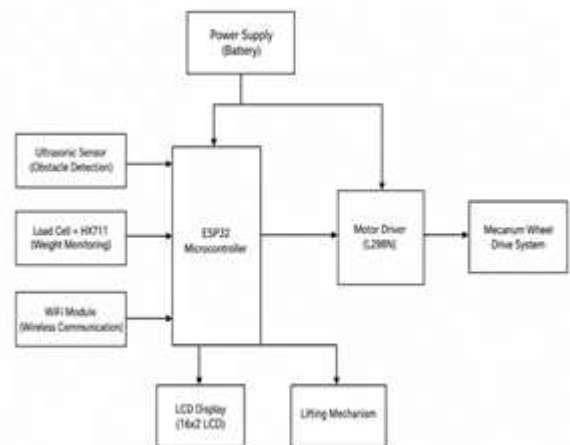


Fig. 1: System Architecture

### B. Working Flow of the System

The overall operation of the proposed OmniLiftBot is illustrated in Fig. 2. The process begins with system initialization, during which the ESP32 controller configures all connected peripherals and sensors. Subsequently, sensor data from the weight monitoring and obstacle detection modules are acquired and processed to determine the current operating conditions of the robot.

Based on the processed information, appropriate control commands are generated and executed to perform the desired actions such as navigation, lifting, or stopping. The system continuously updates and displays the operational status while monitoring sensor inputs in real time. This cyclic process enables reliable decision-making and ensures smooth execution of material handling tasks. The loop continues until the operation is completed or the system is terminated.

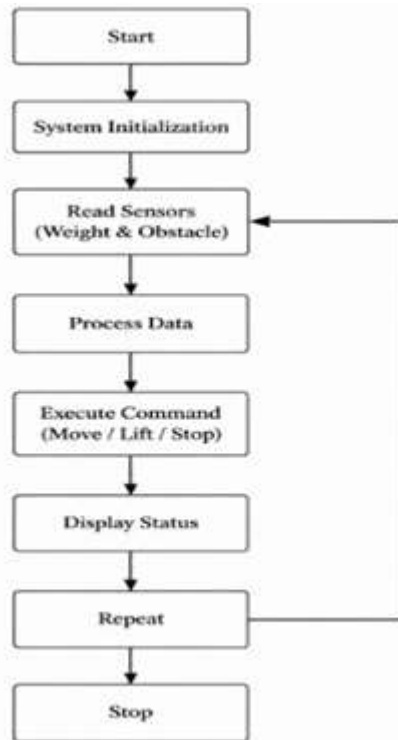


Fig. 2: Flowchart

## B. Hardware Specifications

### Mecannum Wheels

#### 1. What exactly are Mecanum Wheels?

Mecanum wheels consist of rollers attached around the wheel perimeter at an angle of about  $45^\circ$ , allowing the robot to move in multiple directions without changing its orientation. These rollers enable the robot to move in multiple directions such as forward, backward, sideways, and diagonally without changing its orientation. Compared to conventional wheels, Mecanum wheels provide better maneuverability and flexibility in confined spaces.



Fig 3: A Mecanum Wheel

#### 2. Working

The motion of a Mecanum wheel is achieved by combining forces generated by angled rollers, which enables multidirectional movement through controlled wheel rotation. By controlling the rotational direction and speed of individual wheels, the robot can achieve omni-directional movement. This mechanism allows smooth navigation and precise movement in indoor environments.

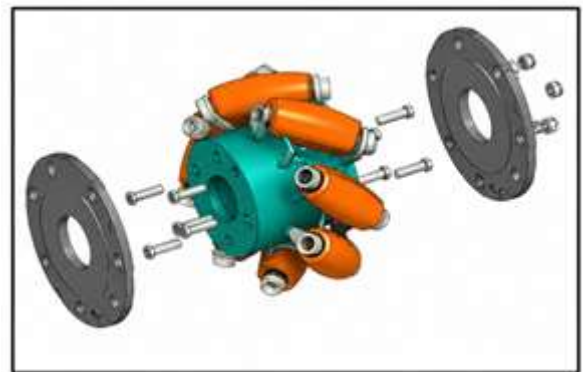


Fig 4: Parts Of Mecanum Wheel

#### C. Scissor Lift Mechanism

The scissor lift mechanism is an important subsystem of the proposed OmniLiftBot, designed to provide vertical motion for material handling applications. Unlike conventional mobile robots that are limited to horizontal transportation, the integration of a scissor lift enables the robot to position loads at different heights, thereby increasing its operational flexibility in warehouse and industrial environments.

The mechanism consists of a set of crossed links arranged in a pantograph configuration. When actuated by a DC geared motor, the crossed links expand and contract, resulting in the upward and downward movement of the platform. This design provides a stable lifting structure while maintaining a compact footprint when retracted.

A scissor lift was selected for the proposed system due to its simplicity, structural rigidity, and ability to support loads uniformly across the platform. The mechanism distributes the load over multiple linkages, reducing stress concentration and improving operational stability. Furthermore, the compact folded structure makes it suitable for integration into mobile robotic platforms where space is limited.

The lifting subsystem enhances the overall functionality of OmniLiftBot by combining horizontal mobility with controlled vertical positioning, making it suitable for smart material handling and warehouse automation applications.



Fig 5: Scissor Lift Mechanism

#### D. Weight Monitoring System

The weight monitoring subsystem of OmniLiftBot is designed using a strain-gauge-based load cell interfaced with an HX711 24-bit analog-to-digital converter. The load cell is mounted beneath the lifting platform to directly sense the force exerted by the payload. Due to the low-level output signal generated by the strain gauges, the HX711 module is employed to provide signal amplification and high-resolution digital conversion before data processing.

The digitized weight data is acquired by the ESP32 microcontroller, where calibration factors are applied to convert raw sensor readings into actual weight values. The processed data is then displayed on the LCD module for real-time payload monitoring. The integration of a high-resolution sensing module improves measurement accuracy and enables reliable weight estimation during material transportation and lifting operations.

The subsystem provides a scalable sensing architecture that can be adapted for different payload capacities by modifying the load cell rating and calibration parameters.



Fig 6: Weight Monitoring System

### III. RESULTS AND DISCUSSION

The OmniLift Bot was tested in controlled indoor conditions to evaluate its performance. The system integrates mecanum wheel-based movement, lifting mechanism, weight monitoring, obstacle detection, and WiFi-based path control to perform smart material handling operations.

#### 1. System Initialization & Load Detection

The system initializes all connected modules after power ON and activates the sensing units. The load cell continuously monitors the payload weight, and the measured value is displayed on the LCD interface for real-time monitoring.



Fig 7: System Initialization

## 2. Path Planning and Navigation

The movement path of the robot is selected through the WiFi-based control interface. Based on the selected path, the ESP32 controls the Mecanum-wheel drive system to achieve smooth omni-directional navigation in indoor environments.



Fig 8:. Path Planning and Navigation

## 3. Obstacle Detection Mechanism

An ultrasonic sensor is used to detect nearby obstacles during robot movement. If an obstacle is detected within the predefined range, the robot temporarily stops operation to ensure safer navigation and collision avoidance.



Fig 9: Obstacle Detection

## 4. Destination & Lifting Operation

After reaching the destination, the lifting mechanism elevates the platform for load handling operation. The mechanism performs controlled lifting and lowering movement for efficient indoor material transportation.



Fig10: Lifting Operation

## 5. Weight Monitoring System

A load cell integrated with the HX711 module is used for real-time payload monitoring. The system continuously measures the load weight and displays the measured value on the LCD for operational monitoring.



Fig 11: Weight Monitoring system

## IV. CONCLUSION

The proposed OmniLift Bot provides an integrated and efficient solution for autonomous material handling applications in warehouses and industrial environments. The system combines Mecanum wheel-based omnidirectional mobility, a scissor-lift mechanism for vertical load transportation, a load-cell-based weight monitoring system, ultrasonic obstacle detection, and WiFi-enabled control within a single robotic platform. This integration enables the robot to perform transportation, lifting, and monitoring operations while minimizing human intervention and improving operational flexibility.

Experimental evaluation of the developed prototype demonstrated reliable performance of all major subsystems

under controlled operating conditions. The Mecanum wheel drive mechanism enabled smooth multidirectional movement, while the lifting mechanism successfully performed controlled elevation and lowering of the payload. The weight monitoring subsystem provided accurate payload measurements, and the obstacle detection module enhanced operational safety by identifying objects in the robot's path. The ESP32-based control architecture ensured effective coordination between sensing, processing, and actuation modules, resulting in stable and efficient system operation.

Overall, the developed system demonstrates the potential of combining embedded control, sensor technologies, and wireless communication to create intelligent material handling solutions. The proposed platform offers a compact, cost-effective, and scalable approach for smart warehouse automation and can serve as a foundation for future enhancements such as autonomous navigation, machine vision, and intelligent decision-making systems.

## REFERENCES

1. J. W. Kang, B. S. Kim, M. J. Chung, "Development of Omni-Directional Mobile Robots with Mecanum Wheels Assisting the Disabled in a Factory Environment," in Proc. Int. Conf. on Control, Automation and Systems (ICCAS), Seoul, Korea, pp. 2070–2075, Oct. 2008.
2. T. Bin Mohamed, N. A. Karim, N. Ibrahim, R. F. R. Suleiman, M. Anwar, and M. F. B. A. Rashid, "Development of Mobile Robot Drive System Using Mecanum Wheels," in Proc. IEE Int. Conf. on Advances in Electrical, Electronic and System Engineering, Putrajaya, Malaysia, pp. 582–587, Nov. 2016.
3. B. I. Adamov, "Influence of Mecanum Wheels Construction on Accuracy of the Omnidirectional Platform Navigation (on Example of KUKA YouBot)," Proc. Russian Federation Robotics Conf., Moscow, Russia, pp. 1–5, 2018.
4. J. S. Keek, S. L. Loh, and S. H. Chong, "Comprehensive Development and Control of a Path-Trackable Mecanum-Wheeled Robot," IEEE Access, vol. 7, pp. 18368–18378, Feb. 2019. DOI: 10.1109/ACCESS.2019.2897010.
5. K. Piemngam, I. Nilkhamhang, and P. Bunnun, "Development of Autonomous Mobile Robot with Mecanum Wheels Assisting the Disabled in a Factory Environment," in Proc. Int. Conf. on Control, Automation and Systems (ICCAS), Seoul, Korea, pp. 2070–2075, Oct. 2008.
6. T. Hongyu and L. Haiyang, "Design Based on Pro/E for a Hydraulic Scissors Lift Platform," Proc. IEEE International Conference on Mechanical and Electrical Engineering, Beijing, China, pp. 210–211, 2011. DOI: 10.1109/ICMEE.2011.6025000.
7. D. Chacón, J. Castillo-G., and A. Aguilar-R., "Electronic System for the Control and Monitoring of Weight Lifting," in Proc. IEEE International Conference on Electronics, Communications and Computing, Cuenca, Ecuador, pp. 1–5, 2018. DOI: 10.1109/ICECO.2018.8538872.
8. B. I. Adamov and G. R. Saypulaev, "A Study of the Dynamics of an Omnidirectional Platform Taking into Account the Design of Mecanum Wheels and Multicomponent Contact Friction," Proc. Russian Federation Robotics Conf., Moscow, Russia, pp. 1–6, 2020. DOI: 10.1109/RCM.2020.87631.
9. A. Benmisra, H. Belaidi, "Hydraulic Model of a Lifting and Handling Manipulator," in Proc. 2020 IEEE International Conference on Electrical Engineering (ICEE), Istanbul, Turkey, pp. 1–6, Sept. 2020.
10. S.-H. Yun, J. Park, J. Seo, and Y.-J. Kim, "Development of an Agile Omnidirectional Mobile Robot With GRF Compensated Wheel-Leg Mechanisms for Human Environments," IEEE Robotics and Automation Letters, vol. 6, no. 4, pp. 8301–8310, Oct. 2021. DOI: 10.1109/LRA.2021.3099954.
11. P. I-T. Chang, C.-C. Liu, S.-C. F. Chiang, and C.-Y. Lan, "Signal-based and Model-based Wheel Fault Detection of Omni-directional Vehicle with Mecanum Wheel," Proc. of IEEE Conf. on Mechanical Engineering, Taipei, Taiwan, 2021.
12. Z. Wang, P. Xu, X. Weng, and Y. Zheng, "Transient Active Short-Circuit Braking Control on Mecanum Drive Wheels in Distributed Electric Vehicles," IEEE Journal of Emerging and Selected Topics in Power Electronics, accepted 2025. DOI: 10.1109/JESTPE.2025.3578523.
13. Z. Wang, G. Wang, and Z. Wu, "Reinforcement Learning-Based Tracking Control for a Three Mecanum-Wheeled Mobile Robot," IEEE Transactions on Neural Networks and Learning Systems, vol. 35, no. 1, pp. 1445–1456, Jan. 2024. DOI: 10.1109/TNNLS.2022.3185055.
14. N. Bami, J. Gudimac, and M. Arigular-R., "Time Pure Pursuit Guidance Control of a Four Mecanum-Wheeled Mobile Robot With Active Disturbance Rejection," IEEE

- Access, vol. 13, pp. 39214–39233, Mar. 2025. DOI: 10.1109/ACCESS.2025.3546864.
15. M. Tang, S. Lin, and Y. Luo, “Mecanum Wheel AGV Trajectory Tracking Control Based on Efficient MPC Algorithm,” *IEEE Access*, vol. 12, pp. 13763–13774, Jan. 2024. DOI: 10.1109/ACCESS.2024.3356583.
16. J. Zhang, S. Lin, and Y. Luo, “ADRC-Based Tube MPC Approach for Trajectory Tracking of Four-Mecanum-Wheel Mobile Vehicle,” *IEEE/ASME Transactions on Mechatronics*, vol. 9, no. 3, pp. 547–558, 2024. DOI: 10.1109/TMECH.2025.3569858.
17. M. Cipriano, O. Oriolo, and A. Cherubini, “Singularity-Free Trajectory Tracking for Steerable Wheeled Mobile Robots,” *IEEE Robotics and Automation Letters*, vol. 10, no. 6, pp. 6199–6207, June 2025. DOI: 10.1109/LRA.2025.3564209.
18. R. Kumar, P. K. Dwivedi, D. P. Reddy, and A. S. Das, “Design and Implementation of Hydraulic Motor Based Elevator System,” *Proc. IEEE Conf. on Industrial Automation, System, Proc. IEEE Conf. on Industrial Automation, Hyderabad, India*, pp. 1–6, 2014