STUDIA UNIVERSITATIS BABEŞ-BOLYAI
Engineering 69(1) 2024 DOI:10.24193/subbeng.2024.1.21

Robotic Assembly – Mobile Platform for Construction Field

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Abstract. *Construction sites often involve the manual transportation of heavy objects, posing risks to workers' safety and efficiency. In this paper, it was proposed a design, development, and evaluation of a service robot specifically created for carrying heavy objects in the construction field. The robot is equipped with robust locomotion capabilities, intelligent perception systems, and efficient control mechanisms to navigate through complex environments and handle various types of loads. It was presented the technical design of the robot, including its hardware components, sensing modalities, and software architecture. Furthermore, it was discussed the experimental validation of the robot's performance in real-world construction scenarios, highlighting its effectiveness in improving productivity, reducing labor costs, and enhancing workplace safety. Through this research, the aim is to demonstrate the potential of service robots as valuable assets in the construction industry, paving the way for future advancements in robotic assistance technologies.*

Keywords: *human-robot collaboration, manipulation, autonomous systems, object transportation, mechanics.*

1. Introduction

The construction industry faces significant challenges with the manual transportation of heavy objects, a task that is both labor-intensive and fraught with risks. Workers frequently encounter physical strain, potential injuries, and inefficiencies while lifting and moving heavy loads, which underscores the need for innovative solutions to enhance safety and productivity [1].

In recent years, the integration of robotics has dramatically transformed various industries, leading to significant improvements in efficiency, productivity, and safety. The construction field, in particular, stands out as an area ripe for innovation through robotics [3]. Advances in robotic technology offer promising solutions to automate labor-intensive tasks, mitigate risks associated with manual handling, and streamline construction processes [2]-[5].

This paper presents a novel contribution to the field by focusing on the development and evolution of robotic platforms specifically designed for construction applications. It addresses in the need for automation in the construction industry by designing and developing a mobile robotic platform optimized for heavy object transportation. The proposed platform is illustrated in Figure 1, showcasing its design and functionality.

Figure 1. Operational robotic platform

Robotic platforms combine different areas of technologies, including autonomous vehicles, drones, mobile robots, and manipulators. These platforms are increasingly recognized for their effectiveness in performing tasks within challenging environments where traditional human intervention may be impractical or hazardous [6][7]. In the context of construction, robotic platforms present unique opportunities to automate repetitive tasks, enhance precision, and improve overall efficiency [8].

This research contributes to this evolving field by advancing the design of mobile robotic platforms for construction. The study not only advances the state of the art in robotic platforms but also provides practical insights into how these technologies can be integrated into existing construction workflows to address current challenges effectively.

In summary, this introduction sets the stage for a detailed integration of the development and application of robotic platforms in the construction industry. The work highlights the potential of these technologies to revolutionize construction practices, offering significant improvements in safety, efficiency, and productivity.

1.1. Importance of heavy object transportation in construction

This section introduce into the significance of heavy object transportation within construction operations. It explores various scenarios where the movement of heavy materials, equipment, and structures is essential for project progress. Examples may include transporting construction materials such as bricks, steel beams, or concrete blocks within the site, as well as moving machinery and tools to different locations, as presented in Figure 2 below.

Figure 2. Common construction materials used for transporting

Heavy objects, such as building materials, equipment, and structural components, form the backbone of construction projects, serving as essential building blocks for infrastructure development [9]. These objects range in size, weight, and complexity, and include items such as steel beams, concrete panels, piping systems, and machinery. The efficient transportation of heavy objects is critical for ensuring the timely and cost-effective completion of construction tasks.

1.2. Role of robotics in construction automation

The focus shifts to the role of robotics as a solution to the challenges outlined before. The section discusses how advancements in robotics, particularly in the field of service robotics, offer opportunities to automate tasks traditionally performed by manual labor, a short presentation is visible in Figure 3 [10][11]. It introduces the concept of a service robot designed specifically for heavy object transportation and sets the research for the upcoming discussion on its design, development, and evaluation.

Figure 3. Robots in construction field

This chapter serves to provide a comprehensive overview of the problem domain, establishing the need for innovative solutions such as service robots in the construction industry.

Automation technologies, including robotics and autonomous systems, offer promising solutions to address the challenges of heavy object transportation in construction [12]. By automating the handling and transportation of heavy objects, construction companies can realize several benefits such as:

Enhanced Safety - automated systems reduce the reliance on manual labor, minimizing the risk of workplace injuries and ensuring a safer working environment for construction workers.

Improved Efficiency - automation streamlines construction workflows, enabling faster, more precise, and more reliable transportation of heavy objects, leading to increased productivity and cost savings.

Optimized Resource Utilization - automated systems optimize the use of resources, including manpower, equipment, and materials, resulting in more efficient construction operations and reduced waste.

2. Research methodology

2.1. Differential kinematics of wheeled robots

Differential kinematics is a fundamental concept in wheeled robotics that describes the relationship between wheel velocities and the motion of the robot's end effector (e.g., its center of mass or a designated point on the chassis). In this topic, we explore the differential kinematics of wheeled robots, focusing on how variations in wheel velocities influence the linear and angular velocities of the robot's end effector.

The end effector velocities represent the translational and rotational motion of the robot in its environment. These velocities are typically expressed in terms of linear velocity V and angular velocity ω, which define the robot's motion along its trajectory and its rate of rotation, respectively. The end effector velocities are determined by the velocities of the robot's wheels and the geometric properties of the robot, such as wheelbase and wheel radii.

The differential kinematics equations relate the velocities of the robot's wheels to its end effector velocities. For a differential drive robot with two independently driven wheels, the kinematic equations are:

$$V = \frac{R}{2}(v_r + v_l) \tag{1}$$

$$\omega = \frac{R}{L}(v_r - v_l) \tag{2}$$

where:

V is the linear velocity of the robot's end effector.

ω is the angular velocity of the robot's end effector.

v_r and v_l are the velocities of the right and left wheels.

R – radius of the wheel

L – distance between the two wheels (wheelbase).

These equations describe how variations in wheel velocities affect the linear and angular motion of the robot. By controlling the velocities of the individual wheels, the robot can achieve different combinations of linear and angular velocities, enabling it to navigate along curved paths, rotate in place, or move straight ahead.

2.1.1. Jacobian Matrix

The Jacobian matrix provides a mathematical framework for analyzing the relationship between the velocities of the robot's wheels and its end effector velocities. It is defined as:

$$J = \begin{bmatrix} \frac{\partial x}{\partial v} & \frac{\partial x}{\partial v} \\ \frac{\partial \theta}{\partial v_r} & \frac{\partial \theta}{\partial v_l} \end{bmatrix} \tag{3}$$

where:

x is the position of the robot along the x-axis.

θ is the orientation of the robot (yaw angle).

The elements of the Jacobian matrix represent the partial derivatives of the robot's position and orientation with respect to the velocities of its wheels. By analyzing the Jacobian matrix, roboticists can gain insights into the robot's motion characteristics and design control algorithms to achieve desired motion profiles.

2.1.2. Friction forces in wheeled robots

Friction forces play a crucial role in the dynamic behavior of wheeled robots, influencing both longitudinal and angular motion, presented in Figure 4 and Figure 5. In this subchapter, it was explored the principles of friction forces in wheeled robots and their impact on robot dynamics and control, as Liu Y. et al. in their research.

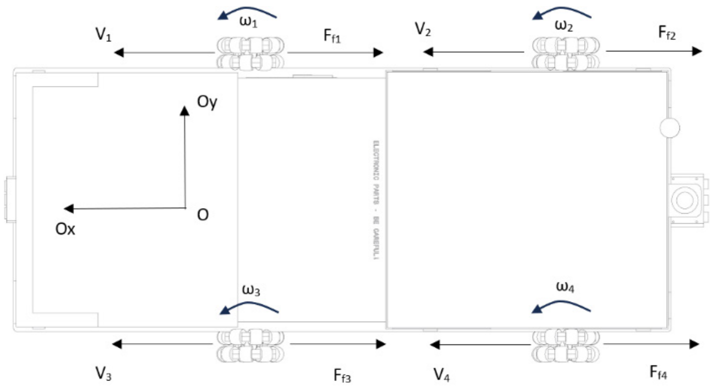

Figure 4. Mobile platform friction forces for longitudinal movement

Longitudinal friction forces occur from the interaction between the wheels of the robot and the ground surface during forward or backward motion. These friction forces affect the robot's acceleration, deceleration, and traction. Key aspects of longitudinal friction forces include:

Static Friction - the maximum friction force that prevents slipping between the wheels and the ground when the robot is at rest or moving at low speeds.

$$F_{static} = \mu_S \cdot N \tag{4}$$

F_{static} - the static friction force.
μ_S - coefficient of static friction.
N – the normal force exerted on the wheels by the ground.

Dynamic Friction - the friction force that opposes the relative motion between the wheels and the ground during acceleration or deceleration.

$$F_{dynamic} = \mu_d \cdot N \tag{5}$$

$F_{dynamic}$ - dynamic friction force
μ_d - coefficient of dynamic friction

Angular friction forces occur when the robot rotates or turns about its axis, influencing its ability to pivot and change direction. These friction forces are particularly important during maneuvering and navigation tasks. Key aspects of angular friction forces include:

Slip-Induced Friction - the friction force that arises when the wheels skid or slide during turning, affecting the robot's stability and control.

$$F_{slip} = \mu_s \cdot N \tag{6}$$

F_{slip} - the slip-inducted friction force.
μ_s - coefficient of friction.

Coulomb Friction - the friction force that opposes the rotational motion of the robot, limiting its ability to change direction quickly and accurately.

$$F_{coulomb} = \mu_c \cdot N \tag{7}$$

$F_{coulomb}$ - the Coulomb friction force.
μ_c- coefficient of Coulomb friction.

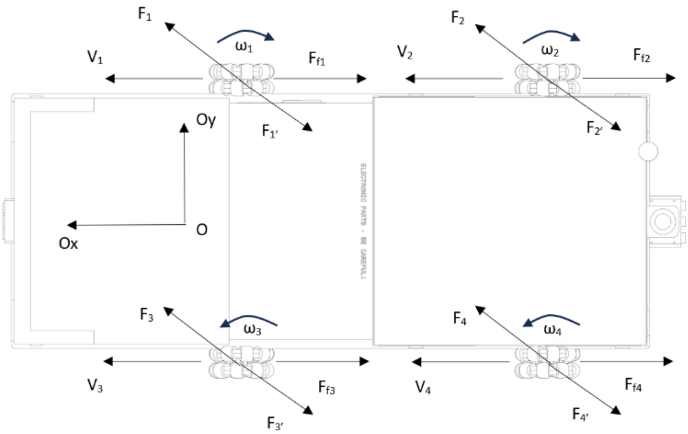

Figure 5. Mobile platform friction forces for angular movement

Friction forces are fundamental aspects of wheeled robot dynamics, influencing both longitudinal and angular motion. By understanding the principles of friction forces and their impact on robot behavior, roboticists can develop effective control strategies and navigation algorithms that optimize the performance and agility of wheeled robots in real-world applications.

3. Mobile platform design: modelling and management tools

This section outlines the specific functional requirements that guided the design of the service robot. It discusses factors such as payload capacity, maneuverability in rugged terrain, compatibility with construction site environments, and safety features to prevent accidents or damage to surroundings and personnel.

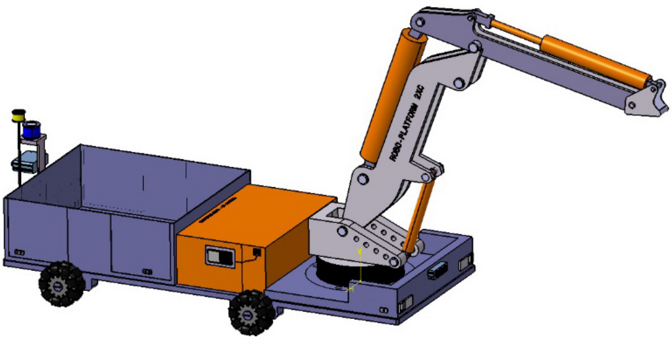

Figure 6. CAD model for the mobile platform

Additionally, it explores design considerations such as scalability, modularity, and ease of maintenance to ensure practicality and adaptability in real-world construction scenarios, the final version of the CAD model can be observed in Figure 6.

3.1. Mechanical structure and locomotion mechanisms

The mechanical design of the service robot is detailed, including its chassis, frame, and locomotion mechanisms. Different locomotion methods, such as wheeled, tracked, or legged systems, are evaluated based on their suitability for navigating construction sites with different terrain and obstacles, based on the research diagram flow presented in Figure 7 below.

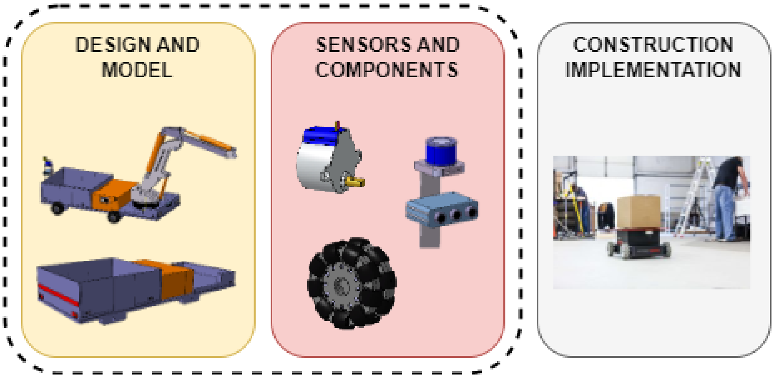

Figure 7. Diagram flow for the mobile-platform structure

The selection of materials and construction techniques to optimize strength, durability, and weight is also discussed, also the main components for the platform, according to Figure 8.

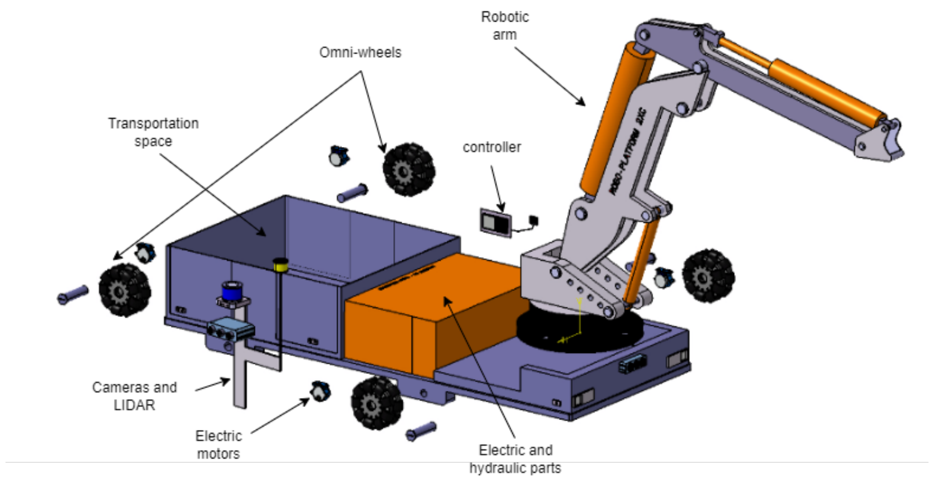

Figure 8. Exploded view with main components

Wheels - wheels are fundamental components of wheeled robots, providing mobility and enabling motion on flat surfaces. The type and configuration of wheels vary depending on the robot's design and intended application.

Omnidirectional Wheels - wheels with rollers or rollers at different angles, allowing for omnidirectional motion. The selected variant is presented in Figure 9.

Figure 9. Omnidirectional wheel used for the platform

Motors - motors are responsible for driving the wheels of the robot, converting electrical energy into mechanical motion. The type and specification of motors depend on factors such as torque requirements, speed, and power efficiency, as the CAD variant from Figure 10.

Stepper Motors - provide precise positioning control and are often used in applications where accuracy is paramount.

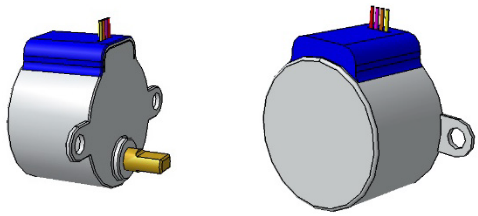

Figure 10. CAD model for stepper motors

Motor controllers regulate the speed and direction of motors, translating control commands from the robot's central processing unit (CPU) into signals that drive the motors. For this research, a stepper motor was used, with the maximum power of 1300W, 25.2 N/m maximum torque Motor controllers vary in complexity and functionality, ranging from simple driver boards to sophisticated motor control units capable of closed-loop feedback control.

Robotic arm - the integration of a hydraulic robot arm into the mobile platform enhances its versatility and functionality, allowing for precise manipulation and handling of heavy objects in construction environments.

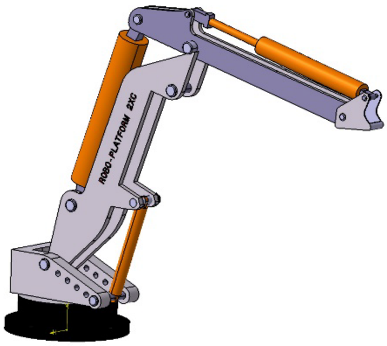

Figure 11. Robotic arm CAD model

While electric robot systems offer certain advantages, such as lower noise levels and greater energy efficiency, hydraulic robot systems excel in applications requiring high power, torque, and ruggedness, the robotic arm is visible in Figure 11 above and mentioned by Chien C.F. et. al in their research. In construction environments, where heavy lifting and robustness are critical, hydraulic systems offer unparalleled performance and reliability.

End tool - the end tool, or end effector, of the robotic arm is a critical component that determines the functionality and versatility of the arm in performing construction activities. In construction settings, various end tools can be attached to the robotic arm to facilitate different tasks, ranging from material handling to precision assembly, as presented in Figure 12.

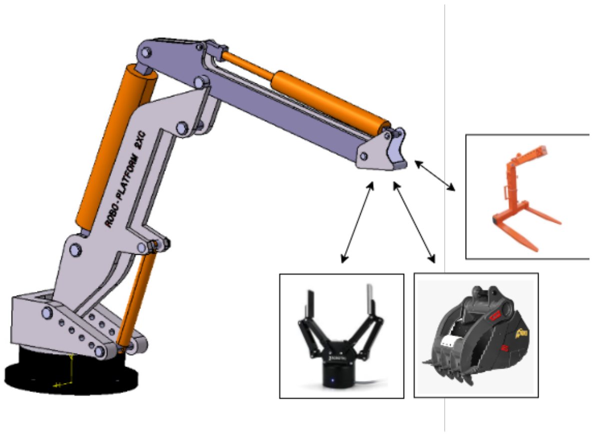

Figure 12. End-tool for robotic arm

Power supply - the power supply provides electrical energy to the robotic platform, powering the motors, sensors, and other electronic components. The power supply system typically consists of:

Batteries - rechargeable batteries are commonly used as the primary power source for mobile robots due to their portability and energy density.

Chassis - the chassis serves as the structural framework of the robotic platform, providing support and housing for the robot's components, from the Figure 13.

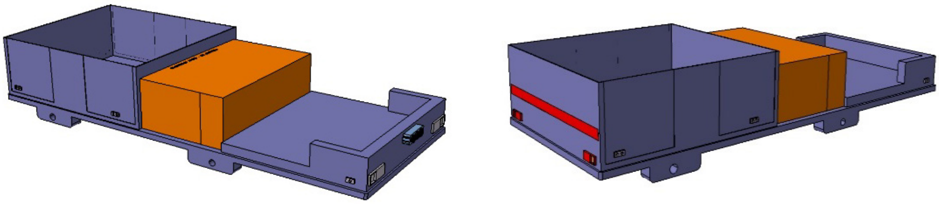

Figure 13. Chassis for the mobile platform

The design and construction of the chassis vary depending on factors such as payload capacity, size constraints, and environmental considerations. Key attributes of the chassis include:

Material - chassis materials range from lightweight metals such as aluminum to durable plastics and composites, balancing strength, weight, and cost considerations. For the following chassis, the material used was aluminium.

Modularity - modular chassis designs allow for easy customization and adaptation to different applications, enabling rapid prototyping and iteration.

3.2. Sensing and perception systems

This section focuses on the sensory capabilities of the service robot, crucial for accurate navigation and object detection in dynamic construction environments. It describes the integration of various sensor modalities, such as cameras, LiDAR, and proximity sensors, to provide comprehensive situational awareness, approached by Boris B. et al. in their work. The choice of sensors, their placement, and data fusion techniques to enhance perception and robustness are explored and presented in Figure 14 and Figure 15.

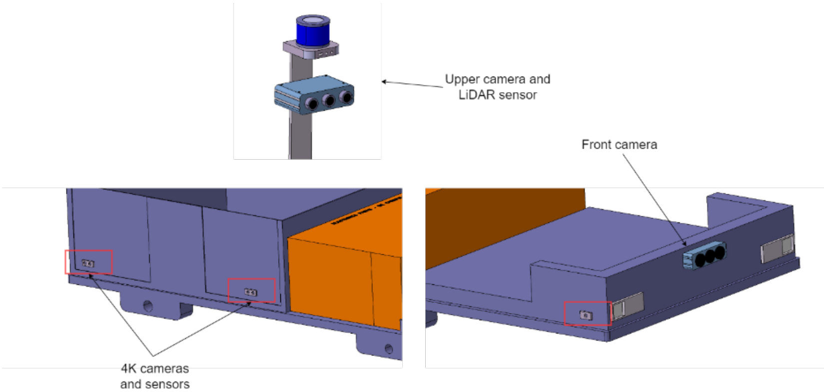

Figure 14. Sensors and cameras on the platform

Vision-Based Object Detection - details the use of cameras and computer vision algorithms to identify and classify objects in the robot's vicinity, enabling it to recognize obstacles, equipment, and materials.

LiDAR for Environment Mapping - discusses the utilization of LiDAR sensors for generating detailed 3D maps of the robot's surroundings, facilitating accurate localization, navigation, and obstacle avoidance.

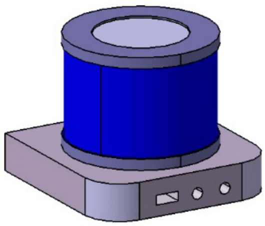

Figure 15. LiDAR sensor

The robotic platform described herein integrates LiDAR (Light Detection and Ranging) sensors and cameras to effectively identify and detect humans in its vicinity. This platform represents a sophisticated solution designed to enhance safety, security, and efficiency in various environments, including industrial settings, construction sites, and public spaces.

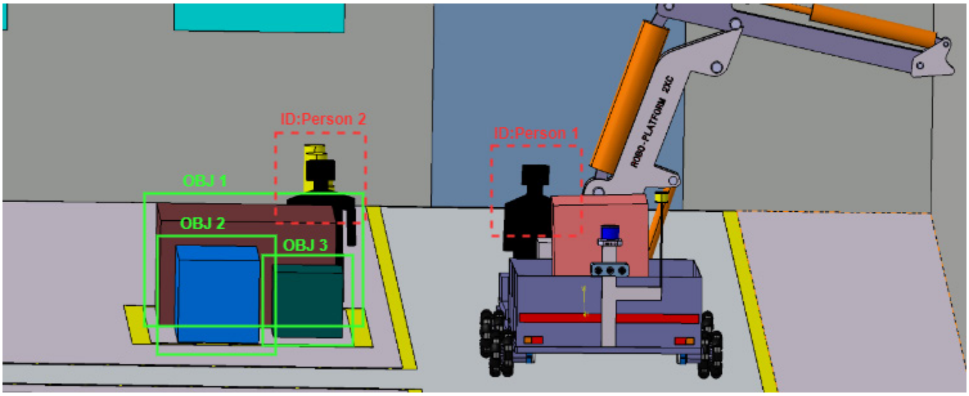

Figure 16. Human identification and avoidance software

This robotic platform is specifically designed to autonomously follow predefined path lines in construction fields, providing efficient and precise navigation capabilities. Equipped with advanced sensors and control systems, the platform seamlessly traverses construction sites, ensuring accurate positioning and adherence to designated routes.

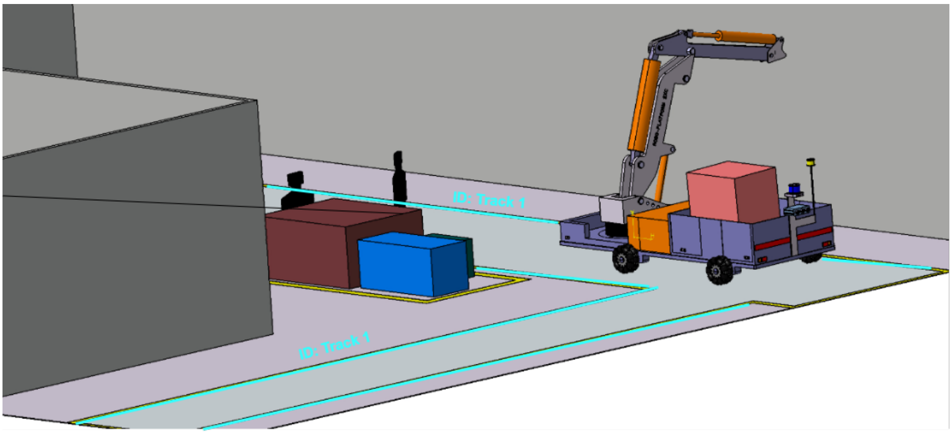

Figure 17. Path follow for the robotic platform in construction field

The robotic platform for path following in construction fields offers a versatile solution for enhancing navigation, efficiency, and safety in construction operations. By autonomously following predefined path lines, the platform streamlines workflows, minimizes human intervention, and maximizes productivity on construction sites, a good working example is presented in Figure 17.

4. Benefits and implications

This section discusses how the deployment of the service robot for heavy object transportation can lead to significant improvements in construction efficiency and productivity. By automating labor-intensive tasks, the robot reduces reliance on manual labor, minimizes downtime, and streamlines workflow processes.

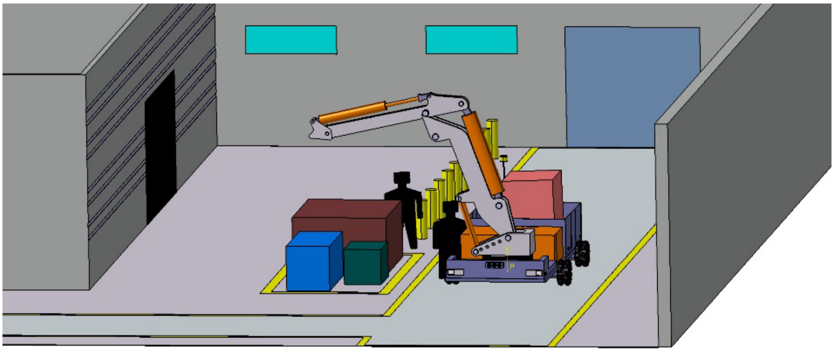

Figure 18. Robot environment functionality

Furthermore, it enables the optimization of resource utilization and project scheduling, ultimately accelerating project completion timelines and reducing overall costs.

The potential relation between the service robot and existing construction equipment and processes are explored and hightlited in Figure 18. The chapter discusses how the robot can seamlessly integrate with other automated systems, such as construction drones, autonomous vehicles, and building information modeling (BIM) software, to create a cohesive ecosystem of robotic assistance. Additionally, it examines opportunities for customization and adaptation of the robot to specific project requirements, enabling tailored solutions for different construction applications and environments.

Through a comprehensive analysis of the benefits and implications of deploying the service robot in construction operations, this chapter highlights its transformative potential in reshaping traditional construction practices.

5. Conclusion

This paper presents the original design, development, and validation of a service robot specifically engineered for the transportation of heavy objects in construction environments. The key contribution of this work is in the creation of an autonomous robotic platform capable of addressing some of the most significant challenges in construction, such as labor shortages, safety concerns, and the need for improved efficiency in material handling tasks.

Also, this research achieved several key contributions toward the development of a service robot created for use in the construction field, such as:

- Design of the robotic platform: the study presents a comprehensive design of a robust robotic platform created for construction sites. The platform is designed to handle heavy objects. The design includes a selected wheel system to ensure smooth movement across construction environments.
- Development of the robotic arm: the design and integration of a hydraulic robotic arm. The choice of hydraulic actuation over electric motors is one of the study's key innovations, allowing the arm to lift and manipulate heavy loads higher than the capacity of electric systems.
- Motion mechanism and control architecture: a motion control system was developed to enable precise movement of the robot. The control architecture incorporates feedback from integrated sensors (e.g., LiDAR, cameras) to adjust speed, direction, and stability in real time.
- Integration of sensors for navigation and object detection: The sensor suite approach combines data from these to enhance the robot's ability to detect and avoid obstacles, identify humans, and navigate safely through construction sites.

The contribution of this research is the development of a fully autonomous service robot specifically designed for construction labor tasks, with a focus on the transportation of heavy objects. The integration of the mechanical and sensor components allows the robot to perform tasks such as material handling, site inspection, and worker assistance, reducing manual labor.

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