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MOBILE ROBOTS FOR LIFTING AND TRANSPORTING OBJECTS OF ANY SHAPE – A REVIEW

BY

ALIN-ȘTEFAN DIACONU[1,*] **and IOAN DOROFTEI**[1,2,3]

[1]“Gheorghe Asachi” Technical University of Iași, Faculty of Mechanical Engineering, 43,
Prof. D. Mangeron Blvd., 700050, Iași, Romania
[2]Technical Sciences Academy of Romania, 26 Dacia Blvd, 030167 Bucharest, Romania
[3]Academy of Romanian Scientists, 3 Ilfov, 05004 Bucharest, Romania

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Abstract. The integration of robotic systems in industrial, logistics, and service environments has accelerated due to rising demands for automation and efficiency. While traditional robots excel in repetitive tasks within structured settings, they face limitations with irregular objects and dynamic conditions. This has led to the emergence of mobile robots as a solution for flexible and scalable operations. This paper reviews the development of robotic systems designed for co-manipulation and transportation of objects of varying shapes and sizes. Emphasis is placed on adaptive gripping technologies, modular designs, and hybrid control architectures combining centralized and distributed coordination. Equipped with advanced sensors and real-time decision-making algorithms, these robots address key challenges in unstructured environments. The study outlines their benefits for applications in logistics, manufacturing, and rescue, while bridging gaps in existing research on irregular load handling.

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[*] Corresponding author; *e-mail*: alin-stefan.diaconu2@student.tuiasi.ro

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1. Introduction

In the evolving landscape of industrial automation, mobile robots have increasingly gained relevance due to their ability to autonomously navigate complex environments and assist with material handling tasks. Traditionally, industrial robots have been fixed, task-specific machines optimized for repetitive operations in structured settings. However, the modern need for flexibility and the handling of objects of various shapes, sizes, and materials has led to the rise of collaborative mobile robots (CMRs).

CMRs represent a new generation of autonomous systems designed not only to move freely in a workspace but also to interact with humans and other robots in a safe and efficient manner. They are typically equipped with omnidirectional wheels, depth sensors, machine vision, and robotic arms capable of gripping objects of diverse geometries. Their deployment spans multiple industries, including logistics, manufacturing, healthcare, and public services.

Unlike traditional automation setups, CMRs are designed to operate in unstructured or semi-structured environments, adapting their behavior based on real-time data from their surroundings. This requires robust localization, mapping, obstacle avoidance, and path planning algorithms. Recent advancements have demonstrated how multi-robot cooperation can be leveraged to transport large or irregular items, distributing the load across several autonomous units while maintaining synchronized motion (Bultmann *et al.*, 2021; Chiriatti *et al.*, 2021; Engemann *et al.*, 2020). The primary motivation behind the development of such systems is to increase operational efficiency, reduce physical strain on human workers, and allow faster adaptation to changing production needs. Robots capable of lifting and transporting objects of any shape must be equipped not only with adaptive manipulators but also with coordinated control mechanisms, especially in multi-robot scenarios (Chen and Lin, 2022; Neri *et al.*, 2022). Moreover, the adoption of collaborative robots in logistics and manufacturing has been accelerated by their ability to share workspaces with humans without requiring caging or isolation. This is made possible through embedded safety protocols, real-time perception, and learning-based control strategies (Boysen *et al.*, 2021; Bonci *et al.*, 2021). Their use also aligns with sustainable goals, as they contribute to energy-efficient transport and optimized space utilization in warehouses (Vaitheeswaran *et al.*, 2014; Ge *et al.*, 2024). Current research continues to address several challenges, such as real-time trajectory coordination between multiple robots, stable gripping of unbalanced or deformable items, and adaptive response to dynamic obstacles. The integration of artificial intelligence (AI), machine learning, and cloud robotics further expands the potential of CMRs to operate with minimal supervision while improving over time (Adithya and Panchal, 2022; Ge *et al*., 2024).

This paper aims to provide a comprehensive review of the technologies, methods, and applications surrounding collaborative mobile robots for lifting and transporting objects of any shape. It explores both hardware and software components, outlines various control architectures, and presents real-world case studies and scenarios where such robots are currently being deployed or tested.

2. Collaborative mobile robots for lifting and transporting irregular objects

The design and implementation of CMRs for object transportation is a multidisciplinary engineering challenge that combines mechanical flexibility, sensor integration, artificial intelligence, and advanced control architectures. These systems must perform complex tasks, such as identifying an object's shape and mass distribution, adjusting their gripping configuration in real time, and coordinating with other robots for safe and efficient movement. The added requirement of handling objects of any shape including deformable, fragile, or asymmetrical items makes this problem space highly dynamic and nontrivial. At the Massachusetts Institute of Technology (MIT), researchers have developed an innovative algorithm for planning multi-robot gripping in sequential assembly operations (see Fig. 1). This algorithm addresses the challenge of coordinating multiple robots that need to grab and assemble parts in a specific order, optimizing efficiency and reducing planning time. Link to multi-robot systems: Multi-robot systems involve collaboration between multiple robots to perform complex tasks.

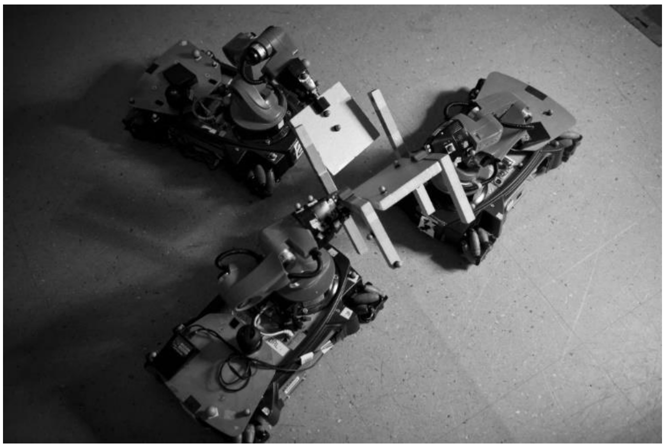

Fig. 1 – Multi-robot gripping planning for sequential assembly operations (MIT researchers' team).

Modern CMRs are typically composed of a mobile platform, which may be omnidirectional or differential-drive, and one or more manipulators mounted on top or at the sides. The manipulators are equipped with adaptive grippers, which can be either underactuated mechanical claws or soft actuators with embedded sensors. These grippers are capable of conforming to the shape of the object, applying the optimal force to maintain a secure grasp without damaging the item (Lin and Huang, 2021; Zaccaria *et al.*, 2021). From a mobility perspective, robots must navigate through potentially cluttered, human-shared environments. They rely on simultaneous localization and mapping (SLAM), obstacle detection, and kinodynamic planning algorithms to generate smooth, collision-free trajectories (Bonci *et al.*, 2021; Chen and Li, 2024). Furthermore, the robots must constantly share data with one another, using wireless communication protocols to exchange localization, grip force feedback, object characteristics, and task status updates (Chen and Lin, 2022; Adithya and Panchal, 2022).

One of the main challenges in mobile robotics is the effective coordination of multiple autonomous agents to perform cooperative tasks such as lifting, holding, and transporting objects of arbitrary geometry. Traditional robotic manipulators are limited by fixed structures and constrained workspaces, while mobile robots offer greater flexibility but require advanced algorithms to ensure synchronized behavior and mechanical stability.

In this context, the C3Bots platform (Hichri *et al.*, 2014) proposes a novel control and actuation framework for collaborative payload manipulation using modular, identical mobile robots (m-bots). By leveraging local autonomy and global coordination, the system can reconfigure dynamically to accommodate payloads with varying size, shape, and mass, without the need for predefined gripping points or fixed grasping hardware (Hichri *et al.*, 2019a).

The sequence depicted in Fig. 2 synthesizes the key operational stages in the co-manipulation process. These stages integrate perception, control, mechanical actuation, and formation management into a cohesive system architecture. The figure is representative of the global behavior of the multi-robot system as it transitions from approach to payload acquisition and transport.

In Fig. 2a, the process begins with the target reaching phase. Each mobile robot autonomously navigates toward its designated location around the payload. This motion is governed by a decentralized navigation strategy that considers obstacle avoidance, restricted zones, and optimal approach vectors. The goal is to place each m-bot in a configuration that satisfies manipulation criteria while preserving overall formation geometry.

In Fig. 2b, upon reaching the target positions, the m-bots engage in object holding. Each robot establishes a contact with the payload and applies force to ensure a stable grip. The grasp is validated through the Force Closure Grasping condition, ensuring that the object is immobilized and that the collective set of contact wrenches can resist external disturbances.

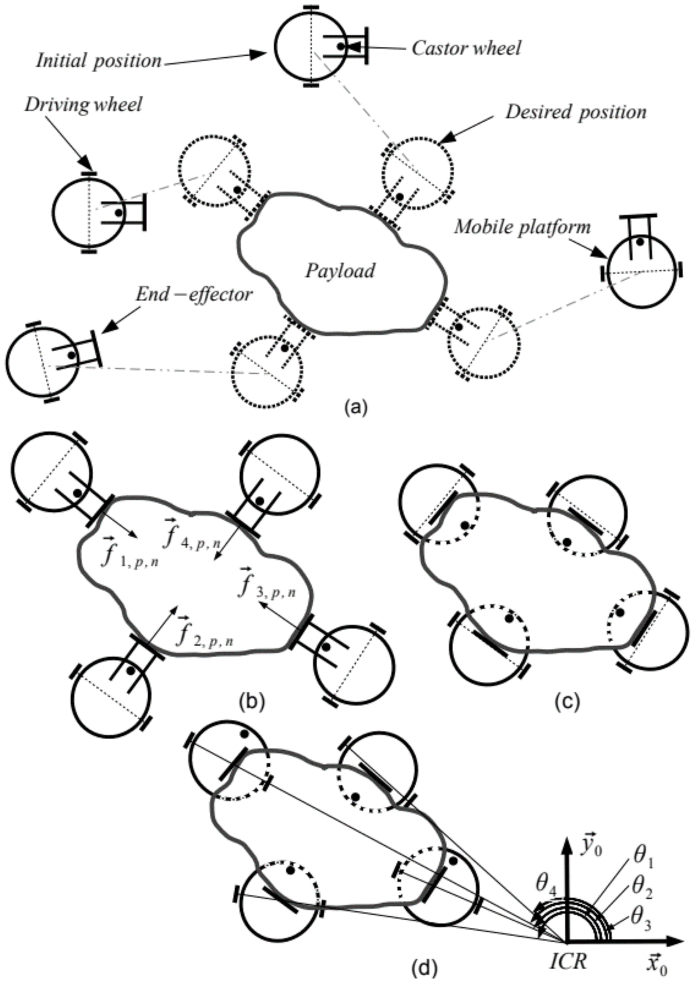

Fig. 2 − Co-manipulation method (Hichri *et al.*, 2019a).

In Fig. 2c, the system transitions to object loading, where the payload is lifted from the ground and placed securely on the robots' upper surfaces. This stage involves the actuation of lifting mechanisms, either passive or powered, and considers the robot configuration such that the payload's center of mass lies within the convex hull of the support base, satisfying the Static Stability Margin constraint.

In Fig. 2d, the m-bots begin collective transport of the payload as a unified formation. The system is now treated as a single poly-robot (p-bot), and its movement is coordinated using a Virtual Structure (VS) approach. Each m-bot computes its own steering angle θ_m with respect to a shared Instantaneous Center of Rotation (ICR). This coordination allows the entire system to follow curved trajectories while maintaining internal mechanical consistency and avoiding deformation of the formation.

As illustrated in Fig. 2, the co-manipulation process follows a structured sequence beginning with autonomous positioning, followed by grasping, lifting, and coordinated transport of the payload. This systematic approach enables a team of individual mobile robots to temporarily function as a unified system, capable of handling complex manipulation tasks.

To better understand the forces involved in these collaborative operations, particularly during the lifting phase, Fig. 3 presents a more detailed mechanical model. It focuses on how two m-bots work together to lift a payload, highlighting how friction parameters and force distribution impact the efficiency and effectiveness of the manipulation process (Hichri *et al.*, 2016, 2019a, b).

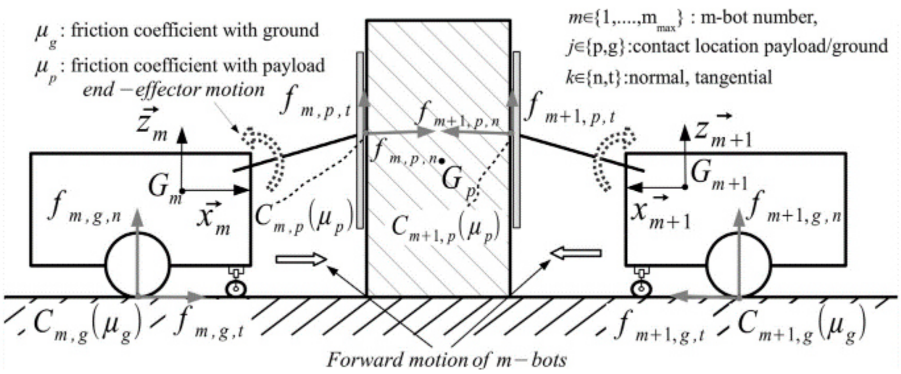

Fig. 3 − Payload lifting by two m-bots (Hichri *et al.*, 2019a).

This model, adapted from Hichri's thesis, underlines how increasing friction coefficients or using more robots increases lifting efficiency. The forces applied by an m-bot during collaborative manipulation tasks are central to understanding how small mobile robots can coordinate to lift or move a shared payload. These forces are represented with a triple index notation $f_{m,j,k}$where m denotes the m-bot number, f indicates the type of contact either ground (g) or payload (p) and k specifies the force component, normal (n) or tangential (t). This notation captures both the interaction of the robot with the ground (through its wheels) and with the object it aims to manipulate.

Each m-bot, with a mass M, can apply a pushing force $f_{m,p,n}$ at the contact point $C_{m,p}$ on the payload. The friction coefficient between the robot and the payload is denoted as μ_p, and it governs how effectively a normal force is converted into a tangential lifting or driving force $f_{m,t}$, via wheel propulsion. Meanwhile, at the contact point with the ground $C_{m,g}$, the friction coefficient μ_g defines the robot's traction capacity. These friction coefficients are crucial in determining whether the m-bot can effectively push, pull, or lift a portion of the payload without slipping (Hichri *et al.*, 2019a, b).

A key insight from this model is that the maximum tangential (lifting or propulsion) force an m-bot can generate is constrained by both the normal force it applies and the friction characteristics of the contacts. The theoretical maximum for the lifting force from a single m-bot is given by the expression:

$$f_{m,p,t}^{\max} = \mu_p \mu_g M_g \tag{1}$$

This indicates that the tangential force is limited by both the ground and payload friction. When assuming simplified and equal friction coefficients $\mu_p = \mu_g = 0.5$, the maximum tangential force simplifies to:

$$f_{m,p,t}^{\max} = \frac{1}{4} M_g \tag{2}$$

From this, we can conclude that increasing the lifting capacity requires either increasing the number of m-bots m_{max}, the mass M of each robot, or the coefficients of friction μ_p and μ_g. However, in real-world environments μ_g and μ_p are not constant, they vary with surface materials, contamination, humidity, and surface roughness. Therefore, accurately estimating the lifting capacity becomes challenging.

To mitigate uncertainty and enhance performance, designers can use high-adhesion materials (such as rubberized wheels or textured contact pads) at the interface between the robots and the ground/payload. This approach increases both μ_p and μ_g, enhancing the robot's ability to apply useful tangential forces without slippage or instability.

The total lifting force available in a cooperative manipulation scenario is the sum of the individual maximum lifting contributions of each robot. This modular and scalable approach to manipulation underpins much of today's research in swarm and cooperative robotics, where multiple small units achieve tasks that exceed the capability of a single robot. This approach also provides robustness and if one unit fails or slips, others can compensate to some degree. This force distribution framework becomes even more relevant in unstructured or dynamic environments, where payload shape and surface properties can change.

As Basmadji point out in the context of space robotics, planning must consider scenarios where conservation of momentum is violated due to flexible or floating environments (Basmadji *et al.*, 2020). Meanwhile, Bobyr describe a fuzzy logic-based system to distribute braking forces among mobile robot engines, adjusting to conditions dynamically to maintain control and safety (Bobyr *et al.*, 2016). Similarly, Haruna explore how different haptic feedback modalities can aid in remote robotic manipulation, showing how perception of force and interaction is fundamental for effective control in shared or uncertain environments (Haruna *et al*., 2021).

3. Systems of mobile robots

In the development mobile robots, the distinction between single-robot systems and multi-robot systems plays a crucial role in the design and implementation of these technologies. Each type of system has specific advantages and limitations, and the choice between them depends on the intended applications, the complexity of the tasks, and the environment in which the robots will operate (Shaheen *et al*., 2014). A single-robot system is typically composed of a standalone, autonomous unit that is responsible for completing all aspects of a given task. These systems are generally easier to design, program, and maintain, due to the centralized control architecture and the reduced number of components involved (Siciliano and Khatib, 2008). They are particularly effective in structured or semi-structured environments where the task flow is predictable and repetitive. One of the most representative examples of such systems is the Omron LD series, including models like LD-60 and LD-90, which are widely used in industrial settings for material transport and object manipulation. These robots are capable of autonomous navigation, obstacle avoidance, and task execution without requiring constant human supervision or coordination with other robotic units. They function as independent platforms that carry out a defined set of operations within a specific workspace.

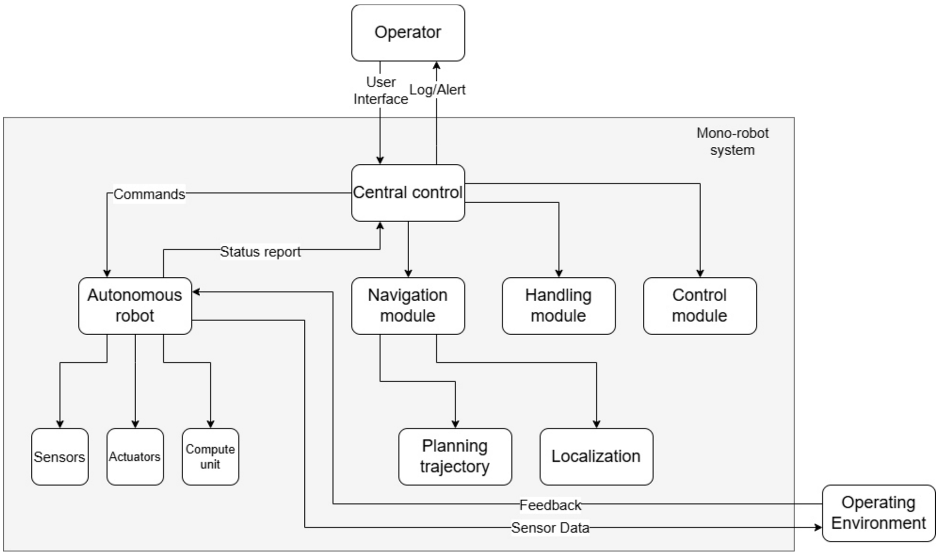

Fig. 4 − Generalized block diagram of the architecture of a mono-robot system.

The main advantage of single-robot systems lies in their relatively low implementation cost and simpler operational structure (Fig. 4). Since only one robot is involved, programming, troubleshooting, and maintaining the system are considerably more manageable. Furthermore, centralized control allows for predictable behavior and direct oversight of task execution. However, the limitations of such systems become apparent when confronted with complex or large-scale applications that demand a higher degree of flexibility or physical capability. In dynamic environments or in cases involving heavy loads, large objects, or simultaneous multi-step operations, a single robot may be insufficient to meet performance requirements (Siciliano and Khatib, 2008).

In contrast, multi-robot systems employ a team of robots that collaborate in real time to complete shared objectives. These systems introduce a layer of complexity associated with coordination, communication, and task distribution but offer significant benefits in terms of scalability, fault tolerance, and operational flexibility (Werger and Mataric, 1997; Parker, 1998). The ability to distribute workload across multiple robotic units enables the execution of tasks that are beyond the capabilities of an individual robot, such as lifting heavy objects, manipulating oversized items, or traversing complex terrain. Multi-robot systems are particularly well-suited for environments where task requirements are variable and where adaptability is crucial.

From an architectural standpoint, modern multi-robot systems often follow a hybrid structure that combines centralized mission planning with decentralized local autonomy. A central controller ensures global task coherence and resource optimization, while individual robots retain the ability to make local decisions based on real-time sensor input. Each robotic unit is a mechatronic system in itself, equipped with advanced sensing modules for both environmental perception and proprioception, as well as onboard processing units capable of real-time data analysis. Communication between robots is typically facilitated through publisher-subscriber protocols, ensuring low-latency information exchange and synchronized coordination. The operational environment is monitored continuously through a distributed sensor network that enhances the collective understanding of spatial and contextual dynamics.

These systems incorporate predictive algorithms that anticipate system states and allow for proactive adjustments to control parameters, ensuring operational efficiency even under variable conditions (Fig. 5). Feedback loops are implemented at multiple levels, ranging from local corrections at the actuator level to global reconfigurations of strategy and behavior. Moreover, multi-robot systems integrate self-diagnosis and fault recovery mechanisms, enabling them to detect and compensate for component failures or performance deviations. Safety is ensured through layered protection strategies, including software limiters and emergency physical barriers. The human-machine interface is designed to be intuitive, providing operators with detailed monitoring tools and control capabilities. One of the most important features of multi-robot systems is their scalability. New robotic units can be seamlessly integrated into the system during runtime thanks to auto-discovery and configuration protocols. Computational loads are distributed intelligently between central and edge nodes, and the system can continuously optimize its own performance through machine learning algorithms that adapt based on accumulated operational experience (KUKA Robotics, 2019).

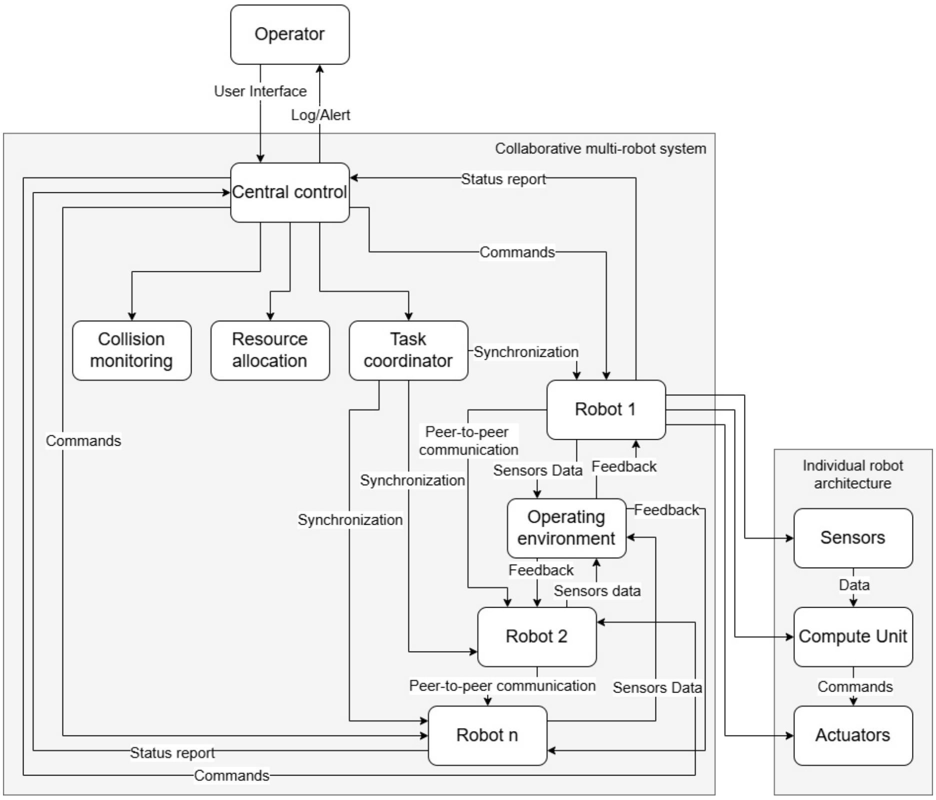

Fig. 5 − Generalized block diagram of the architecture of a multi-robot system.

Table 1 provides a comparative analysis between single-robot and multi-robot systems, highlighting key differences in complexity, scalability, cost, and application. While single-robot systems offer simplicity and lower initial costs, they are best suited for repetitive or localized tasks with minimal environmental dynamics. In contrast, multi-robot systems demonstrate superior scalability, flexibility, and fault tolerance, making them ideal for complex, distributed tasks in dynamic or large-scale environments. However, these advantages come with increased system complexity, higher costs due to communication and synchronization requirements, and the need for advanced algorithms to ensure efficient coordination and safety. The choice between single-robot and multi-robot systems ultimately depends on the specific application requirements and operational constraints, with each approach offering unique benefits tailored to distinct industrial and research contexts.

Table 1

Comparison Between Single-Robot and Multi-Robot Systems

Criterion	Single-Robot	Multi-Robot	Observations/Explanation
Complexity	*Low*	*High*	*Multi-robot systems require advanced algorithms for coordination and collision avoidance.*
Scalability	*Limited to 1 robot*	*Scalable to dozens/hundreds of robots*	*Multi-robots can be added for distributed tasks (e.g., swarm robotics).*
Initial Cost	*Lower (1 robot + simple software)*	*Higher (multiple robots + infrastructure)*	*Costs increase due to communication and synchronization needs.*
Energy Efficiency	*Optimized for individual tasks*	*Depends on collaboration strategy*	*Multi-robots can reduce overall consumption by distributing tasks efficiently.*
Fault Tolerance	*Low (1 failure halts the system)*	*High (redundancy and automatic replacement)*	*If one robot fails, others can take over the task.*
Flexibility	*Limited adaptation to dynamic environments*	*Superior adaptation to complex environments*	*Multi-robots can recalculate trajectories in real-time to avoid obstacles.*
Typical Applications	*- Simple manipulation tasks* *- Local transport*	*- Warehouse logistics* *- Swarm exploration* *- Collaborative assembly*	*Single-robots are preferred for repetitive tasks, while multi-robots are ideal for distributed tasks.*
Communication	*Not necessary*	*Requires robust protocols (Wi-Fi 6, 5G, mesh)*	*Multi-robots leverage ROS 2 or specialized middleware for coordination.*
Safety	*Easy to monitor*	*Requires advanced sensors for collision avoidance*	*Risk of interference between robots demands collision detection systems (e.g., 3D LiDAR).*
Practical Examples	*- UR5 (Universal Robots)* *- Omron LD-60*	*- Kiva Robots (Amazon)* *- Swarm drones (MIT)*	*Single-robots are used in production lines, while multi-robots are common in logistics and research.*

4. Control algorithms

This section presents the results obtained from evaluating various geometric configurations in cooperative object transport using autonomous mobile robots operating in semi-rigid formations. This work aims to evaluate the influence of different formation geometries on collaborative object transport. To achieve this, several semi-rigid multi-robot formations are analyzed. Unlike rigid formations, where both the relative position and orientation of robots remain fixed, a semi-rigid formation allows the relative orientation of the robots in the formation coordinate system $(CS)_F$ to change, while their relative positions $d_i = (dx_i + dy_i)^T$ remain constant. This distinction is crucial when dealing with nonholonomic robots, such as the MiR 600 industrial mobile robot platforms used in this study. Each formation can consist of up to four MiR 600 robots, which feature differential-drive steering. This drive mechanism makes them nonholonomic and not omnidirectional, meaning they must always be aligned with their direction of travel. Consequently, semi-rigid formations are more suitable for these robots than rigid formations (Hichri *et al*., 2014; Recker *et al*., 2023). The target state of the i-th robot, denoted $x_i = (x_i, y_i, \phi_i)^T$, depends on the formation's target pose $x_F = (x_F, y_F, \phi_F)^T$ and its relative position d_i. The transformation for the robot's pose can be mathematically expressed as:

$$\begin{pmatrix} x_i \\ y_i \\ \phi_i \end{pmatrix} = \begin{pmatrix} x_F + \cos(\phi_i) \cdot dx_i - sin(\phi_i) \cdot dy_i \\ y_F + \sin(\phi_i) \cdot dx_i + cos(\phi_i) \cdot dy_i \\ \arctan\left(\frac{\dot{y}_i}{x_i}\right) \end{pmatrix} \tag{3}$$

In the particular case where the relative x-position $dx_i = 0$, the orientation of the robot ϕ_i aligns exactly with the formation's orientation ϕ_F. This flexibility in orientation is a defining feature of semi-rigid formations, allowing robots to adapt their heading while maintaining fixed relative positions.

The literature documents various deterministic approaches to controlling the formation of nonholonomic mobile robots, generally grouped into five categories: virtual structure, behavior-based, leader-follower, graph-based, and potential field methods (Parker, 1998; Hichri *et al*., 2016, 2019a). For tasks requiring very high formation stability such as collaborative object transport, only the virtual structure and graph-based approaches are viable. Virtual structure methods are particularly effective in maintaining a rigid geometric relationship among robots, which is essential for coordinated transport. While virtual structure control suffers from two main disadvantages limited reconfiguration ability and high centralization, these are less problematic in cooperative transport. Since the formation cannot be altered during transport, the inability to reconfigure is irrelevant. Moreover, high centralization is acceptable, as the failure of any single robot would result in the failure of the entire transport operation, necessitating centralized coordination (Shaheen *et al*., 2014; Recker *et al*., 2023).

Accordingly, this work selects a virtual structure approach for formation control. The formation controller uses a modified stable tracking controller, which computes the control output q based on the control error $e = \left(e_x, e_y, e_\phi\right)^T$, proportional control gains $K_{p,x}$, $K_{p,y}$, K_ϕ, integral gain $K_{i,x'}$, and feed-forward velocity $q_r = (v_r, \omega_r)^T$. The control laws for the linear velocity v and angular velocity ω are:

$$v = v_r \cdot \cos\left(e_\phi\right) + K_{p,x} \cdot e_x + K_{i,x} \cdot \tilde{e}_x \tag{4}$$

$$\omega = \omega_r + \mathrm{sgn}(v) \cdot K_{p,y} \cdot e_y + K_{p,\phi} \cdot \sin\left(e_\phi\right) \tag{5}$$

Here, $\tilde{e}_x = \int_0^t e_x(t)dt$ represents the accumulated past control errors, adding an integral action that improves steady-state performance.

This control scheme allows precise and stable coordination among the mobile robots, accommodating their nonholonomic constraints and ensuring that they collectively transport objects effectively by maintaining formation stability and synchronizing their movements. In this study, the target position and velocity of the formation center follow a Lissajous curve with frequency parameters $\frac{\omega_1}{\omega_2} = 2/3$, as illustrated in Fig. 6.

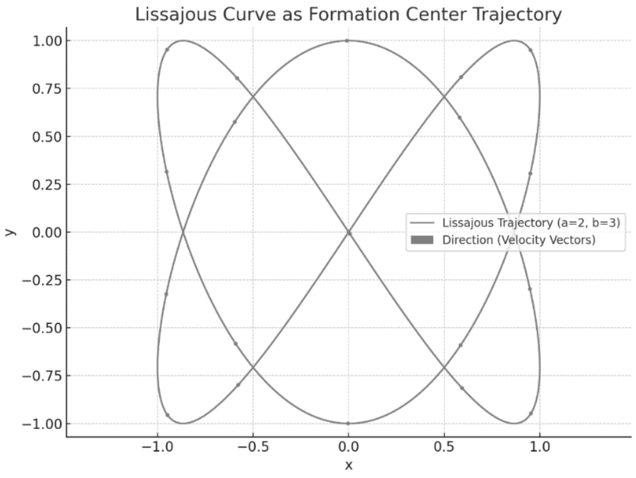

Fig. 6 − Formation center target position and target velocities.

Notably, the robots were required to move in reverse to prevent collisions between the transported object and the manipulators mounted on each mobile platform. To determine the feed-forward velocity input q_r for each individual robot, the formation's linear and angular velocities $q_F = (v_F, \omega_F)^T$ were adjusted based on the robot's relative position $d_i = (dx_i, dy_i)^T$ with respect to the formation center (Recker *et al.*, 2023). The resulting control input is given by:

$$q_r \begin{pmatrix} v_r \\ \omega_r \end{pmatrix} = \begin{pmatrix} v_r + |\omega_r \cdot dx_i| - \omega_r \cdot dy_i \\ \omega_r \end{pmatrix} \tag{6}$$

This computation ensures that each robot's motion contributes appropriately to the overall formation movement while avoiding collisions and maintaining the desired trajectory (Hichri *et al.*, 2019a; Recker *et al.*, 2023).

5. Conclusions

The development of mobile robots for lifting and transporting objects of any shape represents a significant step forward in the field of robotics and industrial automation. This study highlights the need for adaptable and versatile robotic systems capable of meeting the demands of unstructured and dynamic environments. Unlike traditional fixed or task-specific robots, mobile robotic systems designed for object manipulation exhibit a high degree of flexibility, precision, and scalability, enabling them to effectively handle a wide variety of objects regardless of shape, size, or material composition.

Central to these advancements is the integration of innovative hardware and software components, which allow mobile robots to perform complex tasks such as real-time shape recognition, adaptive gripping, and coordinated movement in multi-robot systems. The use of collaborative mobile robots not only improves the efficiency of lifting and transporting operations but also minimizes physical strain on human workers while ensuring safety and sustainability. Techniques such as simultaneous localization and mapping (SLAM), advanced sensing modules, and machine learning algorithms further enhance the ability of these robots to navigate complex environments and adapt to unforeseen challenges. Though current research has yielded promising results, challenges remain, including optimizing trajectory planning, ensuring stable interaction with irregular or deformable objects, and advancing real-time coordination in multi-robot systems. These challenges underscore the need for continued interdisciplinary research into mechanical design, control architecture, and artificial intelligence to fully realize the potential of collaborative mobile robots.

In conclusion, the adoption of mobile robots for lifting and transporting objects of any shape has the potential to revolutionize industries such as logistics, manufacturing, and healthcare. By bridging the gap between flexibility and efficiency, these systems represent a new standard for automation, aligning with modern industrial needs for safety, sustainability, and adaptability.

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ROBOȚI MOBILI PENTRU RIDICAREA ȘI TRANSPORTUL OBIECTELOR DE ORICE FORMĂ – O RECENZIE

(Rezumat)

Integrarea sistemelor robotizate în mediile industriale, logistice și de servicii s-a accelerat din cauza cerințelor tot mai mari de automatizare și eficiență. În timp ce roboții tradiționali excelează în sarcini repetitive în setări structurate, ei se confruntă cu limitări cu obiecte neregulate și condiții dinamice. Acest lucru a dus la apariția roboților mobili ca soluție pentru operațiuni flexibile și scalabile. Această lucrare trece în revistă dezvoltarea sistemelor robotice concepute pentru co-manipularea și transportul obiectelor de diferite forme și dimensiuni. Accentul este pus pe tehnologiile de prindere adaptivă, designul modular și arhitecturile de control hibride care combină coordonarea centralizată și distribuită. Echipați cu senzori avansați și algoritmi de luare a deciziilor în timp real, acești roboți abordează provocările cheie în medii nestructurate. Studiul subliniază beneficiile lor pentru aplicațiile din logistică, producție și salvare, acoperind în același timp lacunele din cercetările existente privind manipularea neregulată a încărcăturii.