Lifting Mechanism for Payload Transport by Collaborative Mobile Robots

B. Hichri, J.-C. Fauroux, L. Adouane, I. Doroftei and Y. Mezouar

Abstract This paper reviews lifting mechanisms and provides a description of a new lifting system that could be fixed on a mobile robot frame. The resulting collaborative mobile robots would be able to transport an object of any shape by lifting it above their transporting platform using the proposed system while keeping a stable formation in order to successfully achieve the task.

Keywords Lifting mechanisms · Collaborative mobile robots · Object manipulation · Transport

1 Introduction

Many industrial tasks (vehicle and construction machine, product manufacturing…) and commercial activities (freight charging, parcel transport) require automated load lifting systems. Industries for which we are interested to develop a robotic system for material lifting and transport are one of the sectors where modern innovative technologies allow to gain better adaptability and productivity.

B. Hichri (✉) · J.-C. Fauroux · L. Adouane · Y. Mezouar
Institut Pascal, Clermont-Ferrand, France
e-mail: bassem.hichri@ifma.fr

J.-C. Fauroux
e-mail: jean-christophe.fauroux@ifma.fr

L. Adouane
e-mail: lounis.adouane@univ-bpclermont.fr

Y. Mezouar
e-mail: youcef.mezouar@univ-bpclermont.fr

I. Doroftei
Gheorghe Asachi Technical University of Iaşi, Iaşi, Romania
e-mail: idorofte@mail.tuiasi.ro

P. Flores and F. Viadero (eds.), *New Trends in Mechanism and Machine Science*,
Mechanisms and Machine Science 24, DOI 10.1007/978-3-319-09411-3_17

Our goal in the C^{3}Bots project (Collaborative Cross and Carry Mobile Robots) is to design several mobile robots with a simple mechanical architecture, called m-bots, that will be able to autonomously co-manipulate and transport objects of any shape by connecting together. The resulting poly-robot system, called p-bot, will be able to solve the so-called removal-man-task [13] to transport any object on the top platform of m-bots (dorsal transport). Reconfiguring the p-bot by adjusting the number of m-bots allows to manipulate heavy objects with any shape, particularly if they are wider than a single m-bot. This particular variant of the C^{3}Bots project will be called C^{3}Bots DGP (Dorsal General Payload transport).

Until now some industrials and constructions still use dedicated equipments that request a long time to be installed. In some cases, manipulated parts are lifted manually to a required altitude. Manual Material Handling (MMH) [15, 21, 22] uses different techniques for object lifting in a safe and efficient way but can cause Repetitive Strain Injuries (RSI).

Diverse mechanisms and technologies are used for objects lifting and transportation. Some transport solutions require heavy infrastructure such as Automated Guided Vehicles (AGV) (e.g. ground landmarks, guiding rails) or specific stacking racks for storage as for Automated Storage and Retrieval System (ASRS). Human assistance could also be needed to put the object on the transporting platform (e.g. scissor [5]). Forklifts [24] use forks to lift and transport the object but they require the positioning of the object on a pallet. Grabbing systems limit the manipulated payload size and shape. According to the previous mentioned systems, one can conclude that for a better stability, an object should be better transported on the robot body [3, 4] or as close as possible to the robot body, to keep the gravity center above the polygon of support and ensure a bigger stability margin.

There are many patented mechanisms for lifting applications with various structures and architectures. In [10], a lifting mechanism for an articulated bed is described. It is based on two parallel arms, hinged to the chassis and the bed plane, which forms an articulated parallelogram with one extendable arm through two segments and equilibrating elastic means. Herrera [11] presents another articulated lifting mechanism comprising a set of arms forming the sides of two rhomboid polygons to lift objects in a vertical direction parallel to the chassis. In [20], the well known lifting jack mechanism, used to lift a vehicle, is presented. Another innovative design [9] is used for a vehicle lifting mechanism using a Y shaped chassis based on a lever, a hydraulic actuator and an articulated support arm. Other example for object lifting and transport is the hand-truck with an innovative design using wheels and a vertical lifter sub assembly [19]. Eppert [7] presents a monitoring payload system for a load lifting vehicle based on a lifting arm and hydraulic actuators. In [8] a lifting mechanism that could be mounted on the rear of truck is described. A mechanism for patient lifting and transport is designed in [23]. Charlec [5] presents a lifting system for metallic parts in construction sites based on a scissor linkage system with metallic bars and a mechanism ensuring the lift up and down movement.

Many robotic systems used for objects manipulation and transportation can be found in literature: [1, 3, 6, 14, 16–18, 25]. The proposed design in this paper is characterized by: the simplicity of mechanical architecture comparing to the systems presented in [3, 25]; the use of a modular swarm of elementary robots [2, 17]; the adaptability to objects of any shape and mass and the ability to provide a fully autonomous system, without human mediation, contrary for example to robotic system proposed in [1, 14].

This overview about lifting mechanisms and manipulation strategies allows to design an innovative robotic system equipped with a lifting mechanism dedicated to payload co-manipulation and transportation. This paper is organized as follows. In Sect. 2 the specification of C^3 Bots project is briefly presented. Section 3 details the developed lifting mechanism structure, provides the dimension analysis and presents the first prototype. Finally, Sect. 4 presents the conclusion and future works.

2 C^3Bots Paradigm

2.1 Specification

The C^3Bots project aims to design identical m-bots equipped with a manipulator. Together they will be able to lift, co-manipulate and transport a payload which has to be laid on the top platform of each m-bot. Consequently, in addition to an end-effector, the m-bot manipulator has to include a lifting mechanism. For simplicity reasons, the end-effector is considered here to be a rigid contact plate in order to fit variable payload contact surfaces. This paper will focus exclusively on the architecture of the lifting mechanism that has to comply with the following requirements R_i: R_1-payload is lifted by several m-bots with unknown number and pose; R_2-collision-free payload trajectory from the ground to the top of robot platform with constant orientation; R_3-mountable mechanism on each m-bot; R_4-a free steering mobility for each m-bot during payload transport. According to this set of requirements, the global co-manipulation methodology will be described and a suitable kinematic structure will be deduced.

2.2 Co-manipulation Method

The proposed co-manipulation and prehension methodology was described in [12]. Figure 1 presents different steps from object detection phase to transport phase. First, m-bots have to locate the object and surround it using distance sensors and turn on themselves so the end-effector faces the object (Fig. 1a). In a second phase, the m-bots collectively hold the object between their end-effectors and exert a collective pressure to hold it using wheel propulsion (Fig. 1b). Submitted to collective pressure and to the proposed co-lifting manipulation, the object is elevated and laid on the m-bots top platform (Fig. 1c). Finally, locomotion and transport is performed where m-bot number m must have a specific steering angle θ_m to ensure a unique Instantaneous Center of Rotation (ICR) of the p-bot (Fig. 1d).

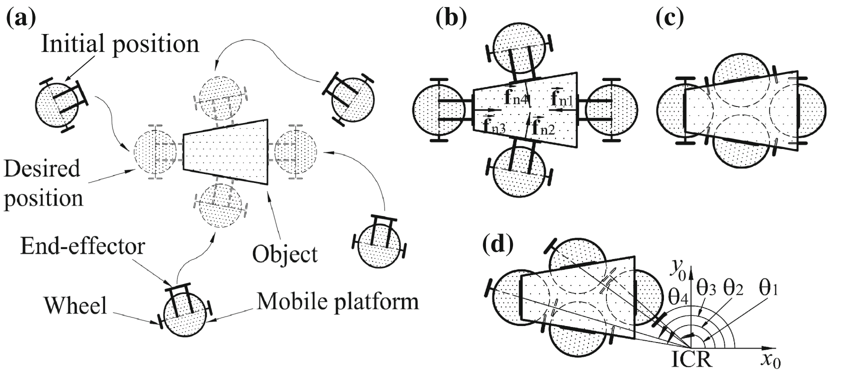

Fig. 1 Co-manipulation method: **a** Target reaching; **b** Object holding; **c** Object set on robot bodies; **d** Object transport: a unique Instantaneous Center of Rotation (ICR) requires different steering angles θ_m

2.3 Pre-dimensioning the Lifting Capacity

A m-bot # m, with a mass M, could apply on the payload a pushing force $f_{m,p,n}$, which generates a lifting force $f_{m,p,t}$, (Fig. 2) counting on wheel propulsion. The contact point $C_{m,g}$ (wheel/ground) is characterized by a friction coefficient μ_g. The maximal lifting force for the m-bot # m can be written as:

$$f_{m,p,t} = \mu_p f_{m,p,n} = \mu_p f_{m,g,t} = \mu_p(\mu_g f_{m,g,n}) = \mu_p(\mu_g Mg) \tag{1}$$

$$\text{The maximal total lifting force is } f_{p,t} = \sum_{m=1}^{m_{max}} f_{m,p,t} = m_{max}\mu_p(\mu_g Mg) \tag{2}$$

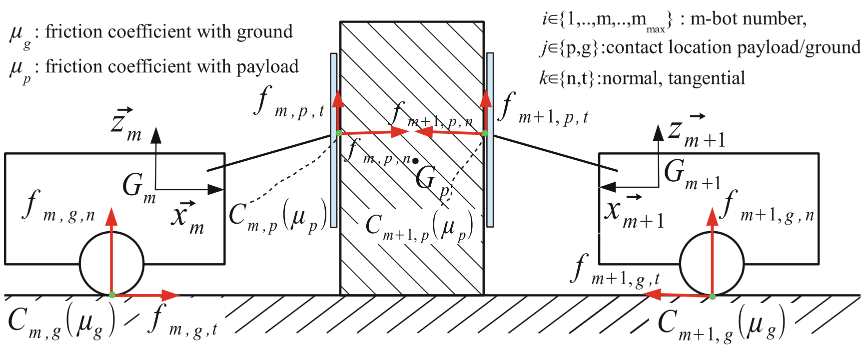

Fig. 2 Payload lifting by two m-bots

With the simplifying assumption $\mu_g = \mu_p = 0.5 \Rightarrow f_{p,t} = \frac{Mm_{max}g}{4}$. One can conclude that to increase the p-bot lifting capacity $f_{p,t}$, the total number m_{max} of m-bots, their mass M or the friction coefficients μ_g and μ_p have to be increased.

3 Designing a Lifting Mechanism

3.1 Structural Synthesis

The various requirements R_i will influence directly the kinematics structure. R_3 and R_4 can be satisfied by supporting the lifting mechanism on a turret. As a consequence, a revolute joint with z axis will support the mechanism (Fig. 1b, c). R_1 defines the initial and final poses P_1 and P_2 of the lower point P of the end-effector that holds the object (Fig. 4). The latter will keep its orientation constant during the lifting motion. The trajectory must start with a vertical lifting motion ($+z_m$) and finishes with a backward horizontal motion ($-x_m$) towards the m-bot platform (Fig. 3a). R_2 implies not to start the horizontal motion too early in order to avoid collision with the m-bot platform. Different trajectories are allowed (Fig. 3a) among which the square and the circular motions are the most obvious. A square trajectory could be achieved using two orthogonal prismatic joints (Fig. 3b) and two actuators. A circular trajectory would lead to a simpler solution using only one actuated revolute joint. However, to keep the payload orientation along the circular trajectory, a parallelogram mechanism is preferred (Fig. 3c) while keeping the control

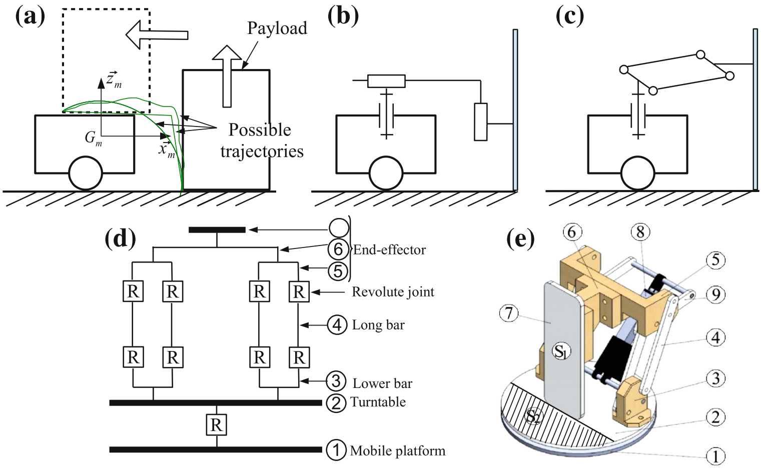

Fig. 3 Elementary lifting systems: **a** Payload initial and final position; **b** 2 DOF solution; **c** 1 DOF solution based on parallelogram mechanism; **d** Binding graph; **e** 3D CAD view

simplicity with a single actuator. The proposed mechanism will be fixed on the top of a unicycle mobile platform.

3.2 Structural Analysis

The proposed lifting mechanism is described in Fig. 3. Part 1 is a base to be fixed on the mobile platform. Part 2 is a turntable connected to 1 via a revolute joint (z_m axis) which allows the robot frame to steer freely when the payload lays on surface S_2 on the top of 2. Two identical parallelogram mechanisms are mounted on 2. Each one is composed of a lower bar 3, two long bars 4 and an end-effector support 5, 6, 7. The end-effector is a plate using the contact surface S_1 to hold the object in collaboration with the other m-bots. A linear actuator 8 is used to ensure object lifting and to control the parallelogram mechanism via an additional lever 9. The actuator allows to maintain the pressure force on the payload.

3.3 Dimensional Synthesis

P_1 and P_2 represents respectively the initial and final positions of lower point of the end-effector P. Two clearance parameters δ_1 and δ_2 are imposed to avoid collision between P and the robot platform during payload lifting at position P_3. Constant and variable parameters are expressed in Fig. 4. Constants are: h-the mobile platform height, l-the distance between P_2 and the front of the robot, clearances δ_1 and δ_2, α_1-the initial angle for the parallelogram mechanism. The synthesis consists in determining the radius of the trajectory $r = l_{AB} = l_{CD}$, then calculating the distance L_1 and finally deducing the positions of A and B:

$$r = l_{AB} = \frac{-m + \sqrt{m^2 - 4np}}{2p} \text{ with } m = -4\{[(l+\delta_1)^2 + \delta_2^2](\delta_2 + 2h\sin\alpha)\}; \tag{3}$$

$$n = 4[(l+\delta_1)^2\cos^2\alpha - \delta_2^2\sin^2\alpha];$$
$$p = -[(l+\delta_1)^2 + \delta_2^2][(l+\delta_1)^2 + \delta_2^2 + 4h(\delta_2 + h)]$$

$$L_1 = \frac{(l+\delta_1)^2 + \delta_2^2 + 2\delta_2(h + r\sin\alpha_1)}{2(l+\delta_1)} + r\cos\alpha_1 \tag{4}$$

$$c = L_1 - r\cos\alpha_1 \tag{5}$$

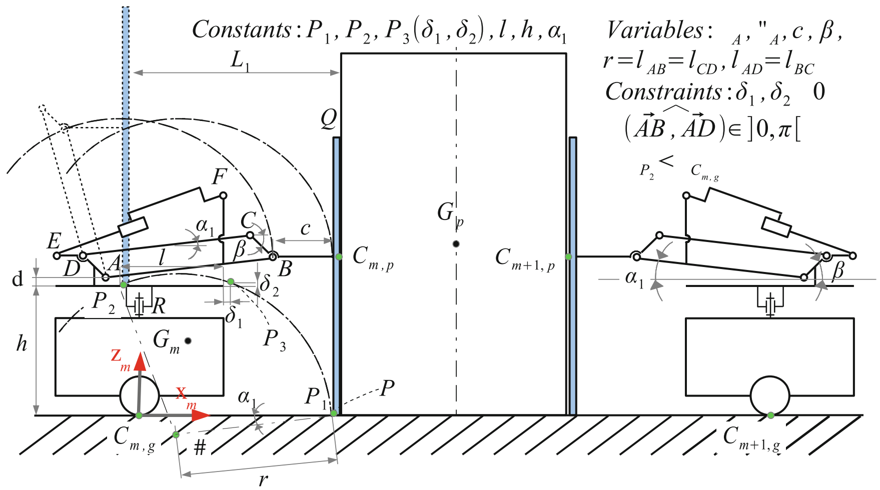

Fig. 4 Dimension synthesis

Now the position of A can be written as:

$$x_A = x_B - r\cos\alpha_1 = x_{P_1} - c - r\cos\alpha_1; \quad z_A = r\sin\alpha_1 + h + d \tag{6}$$

Tha angle β is chosen so that the parallelogram $ABCD$ remains as far as possible from the singular flat configuration in the extreme positions P_1 and P_2. Length l_{AD} is not constrained.

3.4 First Prototype

Figure 5a presents the designed m-bot with the lifting mechanism in a prehension position. Figure 5b illustrates the 3D model for a group of four robots. Two prototypes based on Khepera platform have been realized to validate the manipulation strategy. Each m-bot weighs 1.4 kg. Figure 5c presents two antagonist robots

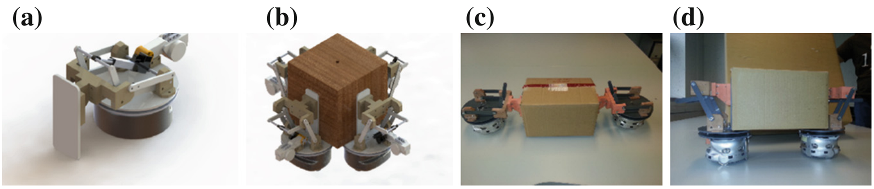

Fig. 5 Model and first prototype based on Khepera platform: **a** First prototype design; **b** Four robots manipulating a box; **c** Box prehension by two robots; **d** Box transport by two robots

manipulating a box (200 × 300 × 200 mm) and lifting it on their bodies. The m-bots keep their end-effectors down and hold the payload in between. Then they lift it up and put it on top of their bodies to be transported (Fig. 5d).

4 Conclusion and Future Work

This paper has presented the paradigm of C^3Bots which aims to co-manipulate and transport a common payload by collaboration between several similar m-bots. Each m-bot is mainly made of two parts: a mobile platform and a manipulation mechanism. A first design of a lifting mechanism to be fixed on the mobile platform has been presented. The developed p-bot is modular and can gather a variable number of m-bots to manipulate an object of a general shape. The m-bot was built from a single-axle robot (Khepera platform). A specific manipulation arm was attached to a vertical actuated and reversible revolute joint to let the m-bot turn freely on itself when the payload is supported by the m-bots. The resulting p-bot is thus allowed to manoeuvre (translation along any direction and rotation around any point in the ground plane). This preliminary design allows object manipulation without considering obstacle climbing which will be the goal of a second part of the project. For future work, experiments are under process for evaluating the transport efficiency with the p-bot. Stability will also have to be evaluated and optimized during prehension, lifting and transport phases while taking into account objects shapes and weights.

Acknowledgments LABEX IMobS3 Innovative Mobility: Smart and Sustainable Solutions, the French National Centre for Scientific Research (CNRS), Auvergne Regional Council and the European funds of regional development (FEDER) are gratefully acknowledged.

References

1. Abou-Samah M, Krovi V (2002) Optimal configuration selection for a cooperating system of mobile manipulators. In: ASME 2002 International Design Engineering Technical Conferences, Montreal
2. Adouane L, Le-Fort-Piat N (2004) Emergence of group intelligence from minimalist control of mobile mini-robots. In: 35th international symposium on robotics ISR
3. Aiyama Y et al (1999) Cooperative transportation by two four legged robots with implicit communication. Robot Auton Syst 29(1):13–19
4. Bay JS (1995) Design of the army-ant cooperative lifting robot. IEEE Robot Autom Mag 1 (36):43
5. Charlec JP (2013) Elevateur pour mise en place des equipements de chantier. French patent FR2987613A1
6. Dorigo M et al (2013) Swarmanoid: a novel concept for the study of heterogeneous robotic swarms. IEEE Robot Autom Mag 20(4):60–71
7. Eppert DA (2012) Load measuring, fleet asset tracking and data management system for load lifting vehicles. Patent WO2012155265A1

8. Fletcher SG, Agg D (2013) Lift for a vehicle. EU patent EP2631117 A1
9. Galla TJ (2013) Lifting mechanism with lift stand accommodation. US patent US2013248786A1
10. Gianfranco G (2009) Lifting mechanism for articulated bed. EU patent EP2108288A1
11. Herrera SF (2011) Lifting mechanism for a storage bed base. EU patent EP2462842A1
12. Hichri B, Fauroux J-C, Adouane L, Mezouar Y, Doroftei I (2014) Design of collaborative cross and carry mobile robots C3Bots. Adv Mater Res 837:588–593
13. Hirata Y, Kosuge K, Asama H, Kaetsu H, Kawabata K (2002) Transportation of an object by multiple distributed robot helpers in cooperation with a human. Trans Jpn Soc Mech Eng 68 (668):1207–1214
14. Hiroaki Y et al (2011) Control of a five-axle, three-steering coupled-vehicle system and its experimental verification. In: Preprints of the 18th IFAC world congress, Milano, pp 12976–12984
15. Hsiang SM et al (1997) Low back pain (LBP) and lifting technique—a review. Int J Indus Ergonomics 19(1):5974
16. Ijspeert AJ et al (2001) Collaboration through the exploitation of local interactions in autonomous collective robotics: the stick pulling experiment. Auton Robot 11(2):149–171
17. Kernbach S et al (2008) Symbiotic robot organisms: REPLICATOR and SYMBRION projects. In: Proceedings of the 8th workshop on performance metrics for intelligent systems, New York, USA, pp 62–69
18. Khatib O et al (1999) Robots in human environments: basic autonomous capabilities. Int J Robot Res 18(7):684–696
19. Kunkel SH, Leatherman JM (2011) Multi dimensional lifting hand truck. US patent US2011052356A1
20. Pino NG (1997) A screw and pentograph lifting jack, particularly for a motor vehicle. EU patent EP0771757A2
21. Plamondon A et al (2014) Lifting strategies of expert and novice workers during a repetitive palletizing task. Appl Ergonomics 45(3):471–481
22. Rabinowitz D et al (1998) Lifting technique and abdominal belt usage: a biomechanical, physiological and subjective investigation. Saf Sci 28(3):155–164
23. Van Oirschot F (2013) Patient lifting device. US patent US2013269103A1
24. Wang JY et al (2010) Innovative design of the lifting mechanisms for forklift trucks. Mech Mach Theor 45(12):1892–1896
25. Wilcox BH et al (2007) Athlete: a cargo handling and manipulation robot for the moon. J Field Robot 24(5):421–434