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# A Mobile Robotized System for Depalletizing Applications: Design and Experimentation

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**ABSTRACT** In this paper, a mobile manipulation system for automatized logistic applications is presented. The robotic system is specifically designed for depalletizing/palletizing tasks, namely is product extraction from homogeneous pallets and assembly of new heterogeneous pallets. The robotic system is mainly composed by an autonomous vehicle, a collaborative robotic arm and a lifting device, which is able to collect products from different pallet layers. The handling strategy is not based on lifting items, as in classical pick-and-place operations, but on dragging them aboard the mobile vehicle. As the payload weight is not supported by the arm, the overall robotic system is very light compared to the manipulated items, which is a paramount benefit for a mobile collaborative application. This paper presents the mechanical design, the hardware selection and the experimentation in a laboratory scenario, thus demonstrating the effectiveness of the proposed manipulation strategy.

**INDEX TERMS** Collaborative robots, depalletizing, dragging manipulation, industrial logistics, mobile robots, palletizing.

## I. INTRODUCTION

This paper presents an automatized robotic device for logistics applications. This work is an extension of the conceptual design reported in [1]. In particular, we present here the prototype design, its physical realization, and the experimentation in a simplified laboratory scenario.

Industrial logistics and product-handling applications received particular benefit, in terms of efficiency and safety, from the introduction of automated robotic system [2]. In particular, handling and palletizing solutions enable to satisfy an ever-increasing market demand, providing a considerable increase in productivity and, at the same time, an improvement in labour conditions. In several applications, such as food and beverage handling, the implementation of robotic solutions has become a standard approach to guarantee high performance and product quality [3]. These solutions generally adopt heavy serial robotic arms to manipulate various types of products, from the lightest to the heaviest. On the

other hand, they are not safe for humans, thus needing to be surrounded by cages, and/or requiring the introduction of safety sensors to detect potential human presence in the robot workspace. These solutions also need high investment costs and they are not flexible, since a robotic arm for logistic applications is usually installed in a fixed position, and it is not suitable for working environments that require dynamic changes, such as different product-line layouts or different types of product to be processed [4]. In many fields that require mixed and flexible tasks, the human operator presence is essential. A robotic system designed to be introduced in these contexts must ensure a high level of safety, without hindering flexibility. A solution that satisfies both requirements is offered by the employment of mobile collaborative robots. This research field has received increasing attention [5]. Usually, collaborative robots (or cobots) are robotic arms smaller and lighter than traditional industrial manipulators [6]. Their low inertia and a series of joint sensors allow cobots to stop quickly if a collision is detected; they are suitable for cooperation with human operators, as they are able to avoid contacts that may cause harm to humans.

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The introduction of mobile bases makes cobots transportable, thus improving flexibility, as a single robotic arm can operate in different modes and stations of the warehouse. In the field of mobile robots, *Automated Guided Vehicles* (AGVs) are a consolidated technology for the transport and distribution of products along a production line. However, traditional AGVs are limited to follow predetermined paths, such as rails or magnetic stripes [7], which causes a lack of flexibility. A technology that can overcome these limitations is provided by *Autonomous Mobile Robots* (AMRs). Thanks to laser and proximity sensors, AMRs are able to detect and avoid collisions with fixed or dynamic obstacles. Moreover, by virtue of a pre-loaded map, they are capable of performing self-localization and autonomous driving within the warehouse [8].

In the area of mobile collaborative robotics, a solution is presented in [9] for adding collaborative features to an industrial AGV. The mobile manipulator is designed for pick-and-place operations of generic-shaped objects, on a simplified pallet. However, it lacks flexibility as the AGV navigation system requires magnetic strips on its path. On the contrary, the two twin mobile manipulators presented in [10] are able to autonomously perform different tasks in an industrial scenario, with particular focus on production, transportation, part-feeding, and assembly tasks. A mobile collaborative robot is presented in [11], which comprises a cobot equipped with vision sensors and a gripping system, installed on an autonomous mobile base. Relevant examples of mobile robotics in industry are provided by the *Amazon Picking Challenge* (APC), for the autonomous picking of 25 different objects [12]. For this challenge, a solution is proposed in [13] in which a collaborative robot is installed on a vertical frame transported by a mobile base; the serial arm is equipped with a suction gripper with 2 Degrees of Freedom (*DoF*) to optimize the product picking point. Instead, in [14] a collaborative robot with 7 *DoF* is installed on a mobile base with holonomic motion capabilities, and it is equipped with a modified vacuum gripper.

Our work is specifically devoted to the development of a mobile robot prototype for depalletizing and palletizing tasks, which frequently occurs in industrial applications. The former term is referred to the decomposition of homogeneous pallets where goods are stored on a rigid platform, and vertically overlapped in several identical layers. The latter term refers to the opposite process, that is the composition of a pallet formed by heterogeneous products, starting from different homogeneous items. In this area, the *MOCA* prototype [15] is a mobile collaborative robot designed for performing mixed tasks in modern warehouses. This solution can operate in different palletizing cases: a generic box can autonomously be handled by the robot or, if it is a heavy or complex-shape product, the handling process can be performed in collaboration with a human operator. The *MOCA* prototype is further developed in [16], by implementing an application for the transportation of pallet jacks. The robotic platform is able to autonomously reach a pallet jack location

and then, by detecting and manipulating its handle, the robot is capable of moving the pallet in different positions of the working environment. A solution for a similar application is shown in [17], where a collaborative robot is installed on a commercial motorized forklift, thus making it possible to both transport a pallet and process products on it. However, the latter system is not capable of manipulating boxes, since the specific gripper design only admits the manipulation of small goods.

Box manipulation usually requires specific robot designs. Cardboard boxes are ordinarily handled by lifting them by means of vacuum grippers [18]. More specifically, the serial arm of the mobile robot presented in [19] is equipped with an adaptive vacuum gripper that allows the box-manipulation strategy to be changed depending on the operating environment. Nevertheless, vacuum technology is not always affordable on a mobile collaborative robot. A manipulation based on a magnetic gripper [20], [21] overcomes such a limitation, but other drawbacks emerge, such as the possibility of handling only magnetic objects. In [21], an electromagnet is placed on the cobot wrist and, in order to make the manipulation possible, a sheet of ferromagnetic material is added on the cardboard-box upper surface.

In general, manipulation methods based on lifting are restricted to packages that are able to sustain their own weight. A different approach is described in [22], where a mobile robot designed for unloading heavy coffee sacks from a container is proposed. The robot is equipped with a chain-conveyor installed on the robot end-effector, which allows a smooth transportation of products by continuously supporting them from below during the unloading process. Another interesting approach is reported in [23], where a mobile collaborative robot is able to manipulate stacked non-rigid objects. Thanks to a custom gripper, the breakdown of a cardboard pile is prevented by dragging products out of the pallet; subsequently, the robot completes the manipulation by lifting and placing the pile on a mobile base.

The manipulation strategy in [23] still involves a part in which the robotic arm lifts the products and must support their weight, which thus is limited by the robot payload capability. Therefore, we propose a different manipulation approach, based on dragging goods aboard the mobile robotized system. In this way, the overall load that acts on the end-effector is reduced, since the latter must not support the payload weight. In this scenario, the mobile robot must be designed to match the handling-by-dragging strategy. The main aim of this article is to describe the mobile-manipulator design, realization and testing.

The paper is structured as follows. Section II gives an overview of the depalletizing process, thus describing the handling approach and the main system requirements. Section III is devoted to the comparison of different hardware and design options, and to the selection of the most suitable ones. Section IV reports some specific features of the mechanical design, whereas Section V describes the experimental test of the prototype in a laboratory scenario. Finally, conclusions

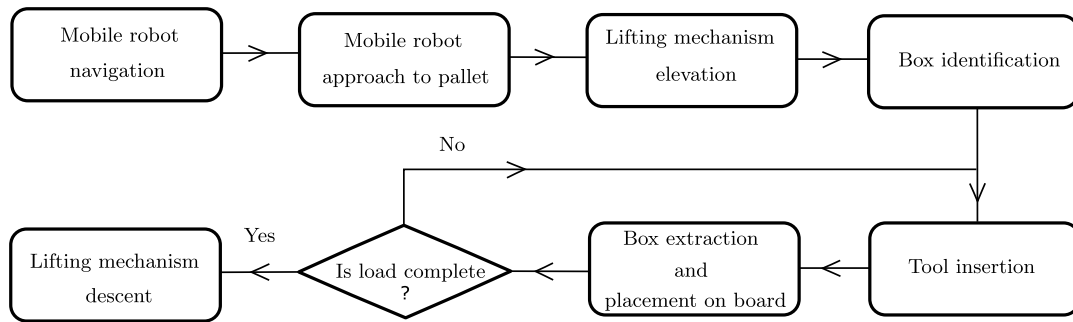


FIGURE 1. Main steps involved in the extraction and placement on board.

are drawn in Section VI. While Sections II through IV are improved and updated versions of the preliminary content presented at the conference [1], Section V is completely new.

## II. SYSTEM REQUIREMENTS

The mobile robotized system described in this paper, called P-COORSA, is suitable for depalletizing (and palletizing) applications in industrial environments. We can divide the depalletizing process in several intermediate steps:

- self-localization of the autonomous robot and navigation from the current location to the desired pallet location.
- detection of the desired item within the pallet;
- product extraction and placement on board.

In this work, we only focus on the last step, i.e. the *product extraction and placement on board* (Fig. 1). During the extraction phase, the autonomous robot is located next to the pallet, at a distance suitable for product manipulation. Then, the system autonomously detects the item to be collected, and the latter is dragged on board. Subsequently, the autonomous robot navigates to the next location and/or collects another item if the space on board is sufficient. The P-COORSA mobile robot is composed by the following components:

- A mobile robot autonomously navigates between different pallet locations.
- A robotic arm manipulates the product. Thanks to the dragging strategy a light-weight cobot can be selected, compared to standard lifting strategies.
- A lifting mechanism receives products dragged from different heights, since the latter are usually stored in pallets made by different layers, separated by interlayer sheets.
- A multi-sensor vision apparatus, mounted on the robot end-effector, detects the products within the pallet. The design and control of the vision system are not discussed in this paper, but in [24], [25].
- Auxiliary mechatronics components, such as actuator boards, emergency stops, etc. are necessary for the overall functionality. In particular, a bespoke device is required to prevent interlayer slipping, which may be caused by the dragging handling strategy.

The products to be manipulated by P-COORSA are packages, in particular cardboard boxes, of approximate dimensions  $150 \times 250 \times 300$  mm, and mass ranging from 2 to 10 kg.

Boxes are stacked upon standard pallets (such as EPAL  $800 \times 1200$  mm), and they form at most 4 layers separated by rigid interlayers (such as cardboard sheets), if placed on the ground.

## III. MECHANICAL ARCHITECTURE AND HARDWARE SELECTION

According to our specifications, we propose to use a serial cobot UR10e provided by *Universal Robot*<sup>1</sup> with a maximum payload of 10 kg, installed on a *MiR100*<sup>2</sup> autonomous mobile robot (AMR) with an admissible onboard load of 100 kg. The cobot and AMR sizes can be conveniently scaled up, depending on the product dimensions, the number of items to be stored on board, etc. The choice of a cobot is due to the fact that the robotized system will have to work in an area shared with human operators (even though the cobot does not have to necessarily interact with them).<sup>3</sup>

As mentioned in Section II, a lifting mechanism (LM) is required to collect products aboard the system from different heights. We choose to use a conveyor on a support that can move vertically. The following subsections discuss the design of the LM and its integration with the cobot and the AMR.

### A. SELECTION OF THE LIFTING DEVICE

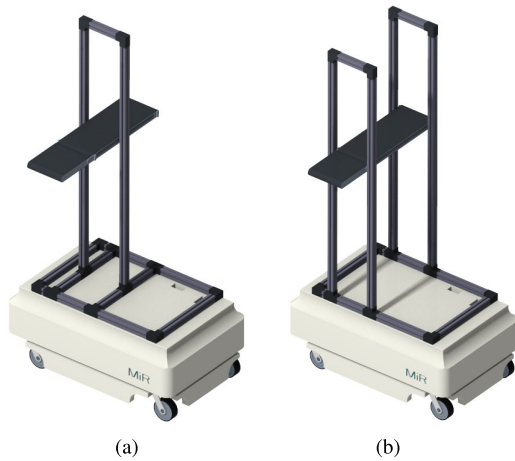
In this subsection, we discuss some possible architectures of the LM mechanisms, and we highlight the main advantages and drawbacks of each solution w.r.t. our specific application. We limit our analysis to the discussion of four designs: a recirculating-ball-bearing guide, a belt-driven mechanism, a telescopic guide, and a scissor lifting mechanism. Each solution is designed to lift a conveyor on the top.

- 1) Recirculating-ball-bearing guide. In this architecture, the LM is composed by a recirculating-ball-bearing unit, driven by an electrical brushless motor placed in a fixed position over the AMR. Thanks to the fixed motor location, the overall center of mass of the LM is located

<sup>1</sup><https://www.universal-robots.com/products/ur10-robot/>

<sup>2</sup><https://www.mobile-industrial-robots.com/en/solutions/robots/mir100/>

<sup>3</sup>It is important to emphasize that the collaborative traits of the system components do not entail the collaborativeness of the overall system. The design refinement of the non-commercial devices (such as the lifting mechanism) to certificate the P-COORSA overall safety according to ISO/TS15006 [26] is the objective of studies that are not reported in this paper.

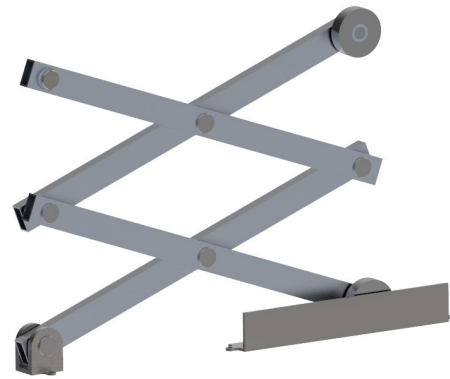


**FIGURE 2.** Frame Configurations for the ball-bearing and belt-driven guides: (a) single frame, and (b) double frame.

closer to the AMR upper surface, thus enhancing the stability of the system. The main components of the LM are commercial products, leading to a simplicity in design. However, the LM frame need to be sufficiently tall to reach the upper layer, and it may reduce the reachable workspace of the robotic arm, since the LM frame may interfere with the cobot. A single or double frame, as illustrated in Fig. 2(a) and Fig. 2(b), can be installed on the AMR to guide the conveyor, with the double frame ensuring better lateral stiffness, but increasing interference problems.

- 2) Belt-Driven mechanism. This solution is conceptually similar to the preceding one, but the guide actuation system relies on a belt transmission. Compared to the ball-bearing guide, this solution provides a simpler and cheaper transmission system, but it may lack load capacity. Also in this solution, a double frame should preferably be employed.
- 3) Telescopic guide. This architecture can be employed to overcome the limitation of solutions (1) and (2) in terms of interference with the cobot workspace: when the telescopic guide is not at the maximum extension, the robot workspace is larger in comparison with designs that include a fixed frame. However, the linear telescopic guide may not reach low layers due to the retracted length of the actuator.
- 4) Scissor lifting mechanism. Such a device is employed in several application domains, such as industrial elevators or rehabilitative applications. Scissor lifting mechanisms, as the one shown in Fig. 3, require an ad-hoc design for the specific application, but they bring a reduced retracted length in comparison with a telescopic guide and larger robot reachable workspace in comparison with ball-bearing and belt-driven mechanisms with fixed frame.

The choice of the optimal solution for our application is performed by considering several aspects of interest, such as design simplicity, cobot reachable workspace, stability of



**FIGURE 3.** Scissor lifting mechanism.

the overall system: the interested reader is referred to [1] for the details of this analysis. As result, the scissor lifting mechanism is selected as the most suitable candidate for our application.

### B. SELECTION OF THE CONVEYOR

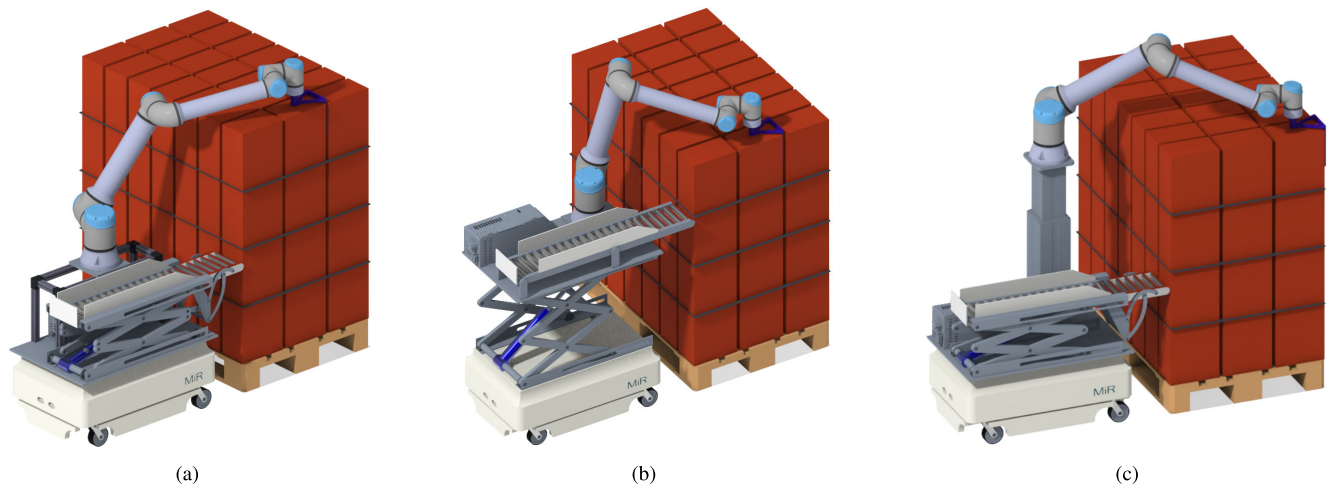
In this subsection, we describe the conveyor selection, analyzing two possible solutions: an idler-roller conveyor and a motorized conveyor.

- 1) Idler-roller conveyor. This solution is based on idle rollers, coupled to a dedicated frame mounted on the top of the LM. The main advantages of this solution are lightness and simplicity, since no motors are required for the roller motion. As a result, also the LM can be lighter. However, a suitable strategy should be implemented to avoid the free movement of the boxes during the AMR navigation.
- 2) Motorized conveyor. Belt conveyors, chain conveyors and motorized roller conveyors are usually adopted when it is important to precisely control the product location. However, motors increase weight, complexity and cost.

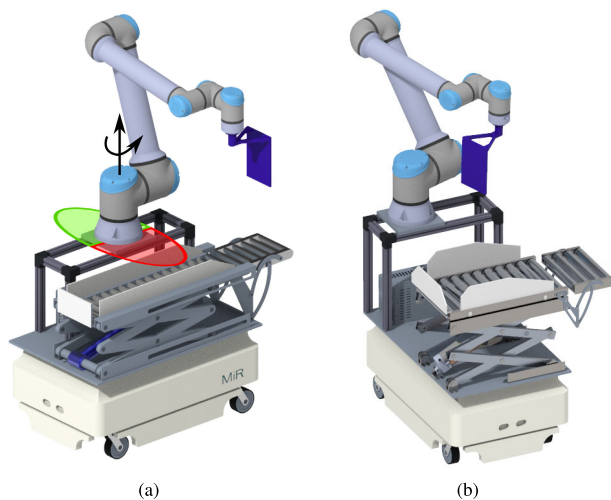
Because of the limited AMR payload, we opted for an idler-roller conveyor mounted on the top of the LM. To overcome the possibility of boxes moving during AMR navigation, the robotic arm can possibly be used to maintain the boxes still.

Due to safety reasons, the AMR must stop at a certain distance from the pallet in order not to bump into it. Moreover, the boxes are usually located some distance away from the pallet outer edge. This results into a gap between the conveyor and the boxes. This empty space may cause difficulties (and box falling) during the dragging process. In order to fill this gap, we propose to introduce a *swivel hatch* (SH). When the AMR navigates through pallets, the SH is retracted and, consequently, the AMR footprint is not significantly enlarged. On the other hand, when the AMR is still and next to the delivery location, the SH opens up and it connects the conveyor and the pallet layer during product manipulation. The choice of the specific SH mechanism is addressed in Section. IV





**FIGURE 4.** Different cobot dispositions: (a) Cobot on a fixed layout (b) Cobot upon the LM (c) Cobot on a telescopic guide.

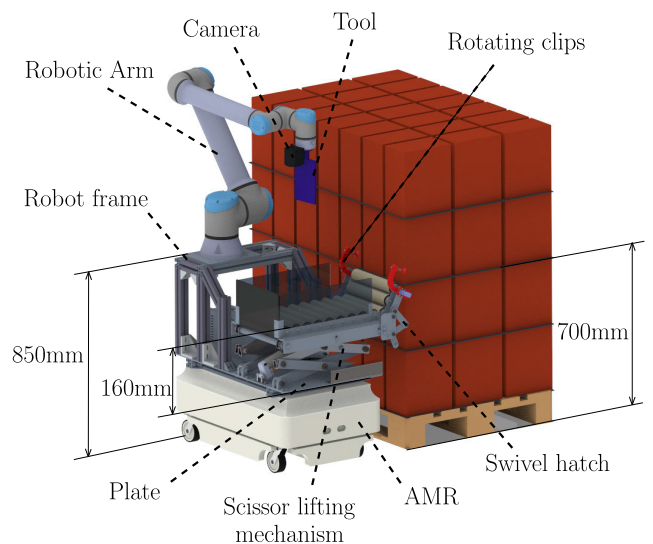


**FIGURE 5.** Different layouts: (a) longitudinal layout (b) transverse layout.

### C. SELECTION OF THE COBOT PLACEMENT

In this subsection, we analyze some possible arrangements of the robotic arm next to the LM. The cobot should be positioned in a location that guarantees the best box manipulability, and at the same time provides sufficient stability of the overall system.

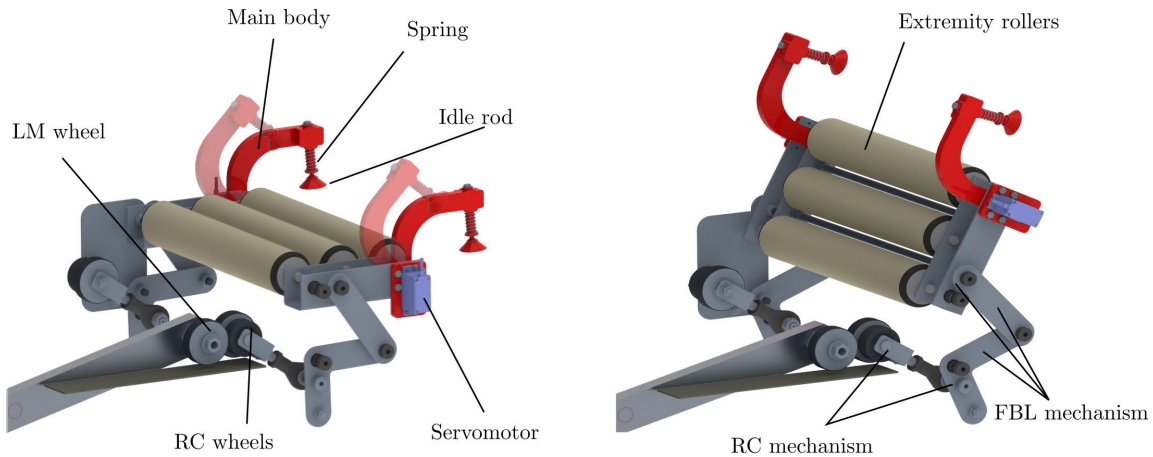
- 1) Robot on a fixed support. In this solution, a fixed frame is installed over the AMR and next to LM, as shown in Fig. 4(a). The cobot is mounted on the top of this frame, and the installation height is selected according to the location of the worst-case box to be manipulated. With this approach, the space below the robot frame can be employed to place several additional components, e.g. the robot control box and LM controllers. In contrast, the fixed location of the robot base may limit the box manipulability range.
- 2) Robot upon the LM. By installing the cobot directly on the top of the LM (Fig. 4(b)), the task execution can be simplified, because conveyor and cobot base always



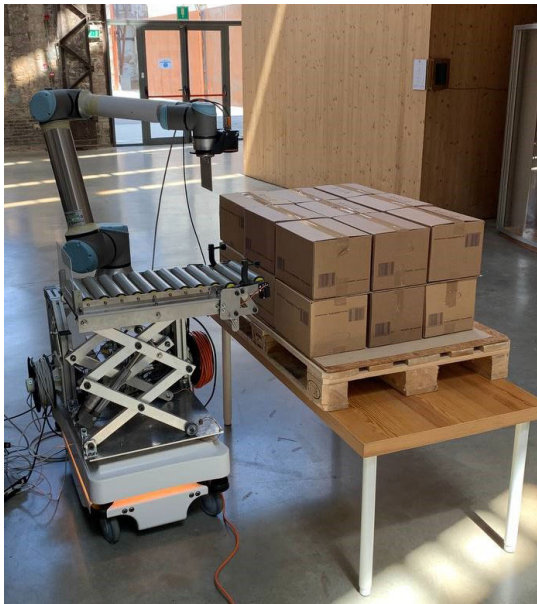
**FIGURE 6.** Prototype design.

- share the same height. In addition, the interference between LM and cobot is drastically reduced and the cobot workspace is considerably enlarged. However, this design makes the LM very heavy, because it must also support the robot weight. The overall stability of the system is also significantly reduced, in particular when dragging boxes placed on the highest pallet layer.
- 3) Robot on a telescopic guide. To resolve the main disadvantages of the robot-upon-LM design, the manipulator can be installed on an independent vertical telescopic guide. However, the cost is increased and stability (determined by the overall center-of-mass height) is penalized, as in the robot-upon-LM design.

The optimal solution is chosen by considering the overall stability of the system, the cobot reachable workspace, cost-effectiveness, and the availability of space aboard the AMR to install additional devices. As a result of this analysis, reported in [1], we decided to place the robotic arm on a fixed support next to the LM.



**FIGURE 7.** Swivel-hatch mechanism and rotating clips. On the left, the swivel hatch is displayed in its open configuration, and the possible motion of the rotating clips is highlighted. On the right, the swivel hatch is illustrated in its closed configuration.



**FIGURE 8.** Experimental setup.

#### D. LAYOUT SELECTION

In this subsection, we discuss two possible layouts for the location of the cobot and the LM on the AMR. The rectangular footprint of the AMR enables us to identify a longitudinal and a transverse layout, as shown in Fig. 5.

- 1) Longitudinal layout. This arrangement ensures a higher stability during cobot operation. However, two main drawbacks may be identified. The first is related to the limitations of the cobot reachable workspace, due to the possible interference between the manipulator and the LM. The base joint of the cobot cannot rotate freely, but there is an interference region, represented in red in Fig. 5(b). Then, in the longitudinal layout, the admissible width of the roller conveyor is significantly reduced (in comparison with the transverse layout), because of the thinner longitudinal AMR

width. Thus, boxes can be collected over the LM only with the short side ahead.

- 2) Transverse layout. With this arrangement, we can overcome the main disadvantages of the longitudinal layout: the cobot-LM interference is reduced and the conveyor have a larger width, so that boxes can be stored with both sides ahead. As a drawback, the overall stability may be reduced.

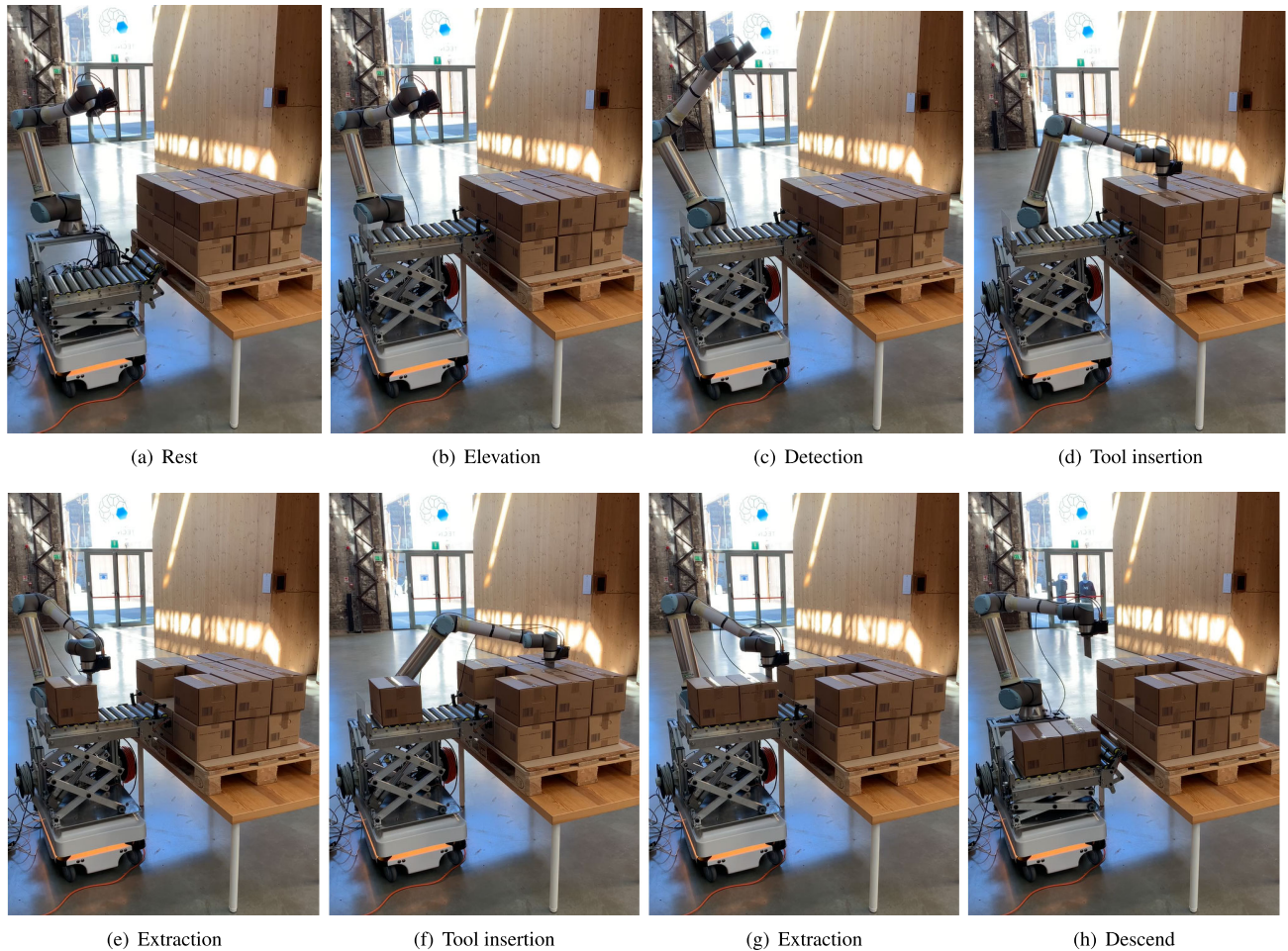
Due to the limitations of the longitudinal layout, we decided to dispose the system components in a transverse layout.

#### IV. MECHANICAL DESIGN

An overall view of the P-COORSA prototype is portrayed in Fig. 6. A plate is mounted on the top of the AMR as a base reinforcement and, at the same time, to provide an easier installation of the LM and cobot frame. The cobot is installed at a height of 850 mm from the ground: this installation provides a good trade-off between stability and reachable boxes, with the cobot being able to manipulate the two boxes closest to the AMR vehicle. The AMR moves to the opposite side of the pallet when a further box has to be manipulated. As an alternative, a robot with a larger reachable workspace can be employed in combination with a larger-footprint AMR.

The LM is made by two scissor lifting mechanisms placed in parallel, connected together by a transverse ledger. Each scissor lifting mechanism, with link length of 460 mm, is designed not to exceed the AMR footprint at the lowest reachable configuration. The LM is driven by a linear DC actuator with a nominal stroke of 160 mm and maximal push force of 3000 N. The width and length of the conveyor are designed not to exceed the MiR footprint and so that three boxes can be collected, if placed with the shorter side ahead. Instead, two boxes can be stored if the longest side is ahead. With the selected actuator, the LM can cover two pallet layers, with an approximate lifting stroke of 600 mm. Starting from a minimal height of the LM (w.r.t. to the AMR base) of 160 mm and considering the AMR height, it is not possible to process





**FIGURE 9.** Sequences of 2-boxes depalletizing task performed by the P-COORSA prototype.

the lowest two layers, if they are placed on the ground over a standard EPAL pallet. A solution is to place the products over a raised support.

The SH is required to close the gap between conveyor and pallet during product manipulation. This mechanism is attached to the conveyor on the top of the LM. A *four-bar linkage* (FBL), as the one in Fig. 7, rotates the last rollers of the conveyor. Despite the possibility of an independent actuation of the FBL (such as a stepper motor), we opted for a passive actuation by a *roller-crank* mechanism (RC), in order to decrease the overall weight. The RC, shown in Fig. 7, is directly actuated by the motion of the LM, thanks to wheels mounted on both RC and LM extremities, pushing each other. Wheels are installed in pairs, in order to avoid possible slipping during the intermittent contact. The operating strategy of the SH is resumed as follows:

- starting from the highest position, when the LM descends, the LM wheels (see Fig.7) move horizontally;
- at a low height, the LM wheels enter in contact with the RC wheels;
- the RC mechanism transforms the linear motion of the wheels into the angular motion of the input link of the FBL;

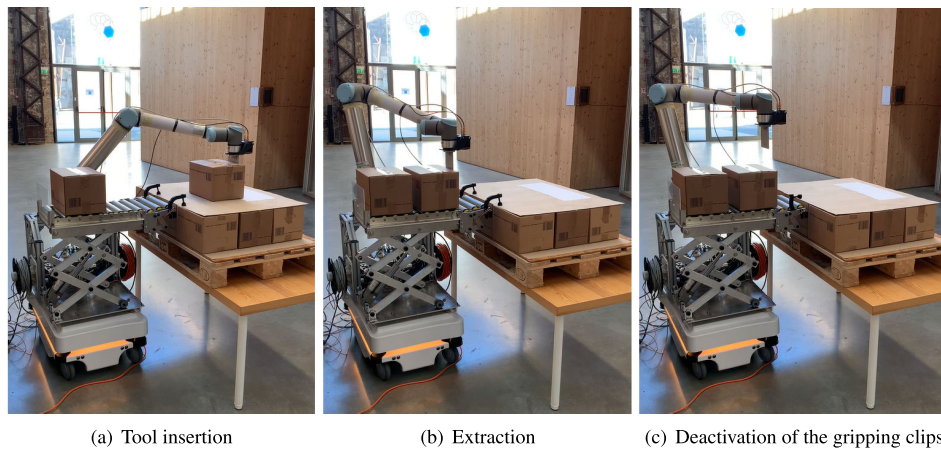
- the SH attached to output link of the FBL rotates.

The SH mechanism is designed to ensure an angular rotation from  $0^\circ$  to  $70^\circ$  in the closed configuration, which corresponds to an approximate vertical movement of the LM of 95 mm from the lowest configuration.

Since friction phenomena may occur during box dragging, an undesired movement of the interlayer may occur. This phenomenon is particularly relevant during the extraction of the last box of each layer, since no other load prevents slipping of the intermediate layer. Thus, a pair of rotating clips are used to hold the interlayer still (Fig. 7). The main body of each clip is actuated by a small-size RC-servomotor with a stall torque of 20 kgcm. Once the SH is opened, the clips are actuated: the main body is rotated, the idle rod of the clip is placed on the interlayer, thus resulting in a spring compression and a force applied on it.

## V. EXPERIMENTAL TEST

In this Section, two experiments conducted in a simplified laboratory scenario are described to show the effectiveness of the adopted manipulation strategy. A video showing the experiments is available in the multimedia section. Two layers of cardboard boxes are collected on a standard



**FIGURE 10.** Extraction of last box of a layer.

800×1200 mm pallet. Accordingly to our specifications, each cardboard weighs 4 kg and has dimensions 310×230×210 mm. The pallet is placed on a raised support, at an approximate height of 680 mm, which places the first and second layer at 780 mm and 1060 mm, respectively. Since in this paper we only focus on product extraction and placement on board, the AMR is placed at a fixed location next to the pallet, as represented in Fig. 8: the vehicle is located so that the conveyor rollers are in front of the boxes to be extracted. A very thin cardboard sheet is employed as interlayer. Despite the possibility of using a thicker interlayer to decrease the possibility of interlayer slipping, the cardboard sheet is tested as a worst-case scenario.

The first experiment is conducted to demonstrate the overall functionality of the dragging handling strategy. Two full layers of 9 boxes are stored on the pallet, and the P-COORSA prototype is required to depalletize two boxes from the higher layer. The extraction sequence is reported in Fig. 9. The operation starts from a rest configuration, with the LM being in its lowest position. The LM is then lifted at the second-layer height (elevation phase) and the cobot is moved to a configuration suitable for the detection phase, where boxes are identified. Subsequently, the cobot performs the box extraction, by first inserting the tool in the gap between boxes and then dragging the closest box aboard the roller conveyor. The operation is then repeated for the second box. Finally, when boxes are stored on the vehicle, the LM is lowered to conclude the depalletizing process. The experiments showed the feasibility of the dragging handling strategy also for considerable box weights, such as 4 kg.

Undesired motion of adjacent boxes during the dragging operation may be caused by lateral friction between boxes. However, we did not notice this phenomenon in our case study. Should this effect be problematic, the depalletizing task may start from the most external item on the pallet. This way, no lateral force compresses the boxes, and lateral friction is accordingly minimized.

The second experiment is conducted to investigate the possible shifting and/or slipping of the interlayer during the

extraction of the last box of a layer. For this purpose, a full layer of 9 boxes is created on the top of the pallet and a partial layer of only two boxes is placed upon the first level. The P-COORSA prototype is commanded to extract the two top boxes avoiding any interlayer movement during box handling. Thus, when the LM is elevated, the rotating clips are activated to exert a force on the interlayer, as shown in Fig. 10. In this way, during the extraction phase of the last box, the interlayer remains still and the depalletizing task is performed successfully. Before lowering the LM, the clips are deactivated. The test showed the effectiveness of the gripping-clip system to prevent the interlayer from slipping with moderate box weight, also in the presence of a very thin interlayer, such as a cardboard sheet.

In case of boxes that are higher than larger or weight is unevenly distributed inside boxes, the latter may become unstable during dragging and flip over, if a simple shovel-shaped end-effector is used (as in our experiments). For this reason, a bespoke gripper, which is supposed to tightly hold boxes of different sizes, is currently under design.

## VI. CONCLUSION

This paper proposed an autonomous robotic system for box depalletizing/palletizing applications. In particular, we referred to the decomposition (or composition) of homogeneous (or heterogeneous) pallets, where boxes are stored on a rigid platform, and vertically overlapped in several identical layers separated by interlayer sheets.

According to traditional manipulation strategies, a robotic arm lifts the box to be handled, thus having to support its weight. This approach requires arms with payload and size increasing with box weight, thus making it difficult to install the robot on a mobile base. Moreover, this approach is unfeasible when the box is not able to sustain its own weight (e.g. heavy cardboard boxes). To overcome such limitations, our approach is based on dragging handled items, rather than lifting them.

The proposed system, called P-COORSA, is composed of an autonomous mobile robot, a cobot and a lifting



mechanism, with the latter two mounted on the mobile robot. The lifting mechanism includes a conveyor, which is kept at the same height of the box to manipulate. The cobot drags the boxes aboard the conveyor, where they are also stored. The mobile system can navigate to/from different pallets, and can share the operation space with humans.

This paper presented the mechanical design, the hardware selection, and the experimentation of the P-COORSA prototype in a simplified laboratory scenario. Experimental tests demonstrate the effectiveness of the proposed handling approach. A limit of P-COORSA is that the lowest layer of boxes that can be manipulated must lie at 700 mm from the ground, since this is the lowest position attainable by the conveyor. This means that the pallet must be placed upon a raised platform.

A bespoke gripper, that improves box stability during the dragging phase, is currently being designed. Our future work will mainly be devoted to improve the safety features of P-COORSA (in particular of the lifting mechanism, e.g. enclosing it within a telescopic case) in order to certify its overall collaborativeness.

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