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Robotic Autonomous Loco-Manipulation For Logistics In Industrial Plants

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***Abstract*—The machine tending in a productive plant typically requires the transport of material from a storage area to a productive area. The plant logistics phase is a part of the production process that is often performed manually, due to the technological challenges related to the manipulation of objects in constrained environments, such as the shelf of a warehouse. However, an effort for its automation is justified by the fact that for an human operator this activity is fatiguing, not ergonomic and with low added value. This paper proposes a control framework for the automation of plant logistics for an industrial case study, integrating navigation and objects manipulation.**

***Index Terms*—Autonomous manipulation in constrained environment, logistics, technology transfer, navigation.**

I. INTRODUCTION

The functioning of a productive plant needs a material flow to feed machines. This flow usually requires the capability of handling and transport objects, often in constrained environments, while being adaptable to process changes. This complexity in many cases have discouraged the automation of logistics. Conversely, the costs of manual logistic operations for human workers are fatigue and overtime musculoskeletal disorders [1]. Hence, the pursue of this work to investigate solutions for the automation of industrial plant logistics, see Fig. 1.

Logistic tasks involve both navigation and object manipulation. While for the former the industry has made significant progress with the introduction of commercial AGV [10], the latter still presents significant challenges. In fact, manipulation requires the definition of effective strategies to grasp and handle objects in constrained environments, it needs to deal with possible collisions with the surroundings, and preferably a robotic solution should be flexible enough to adapt to pre-existing plant layout, to avoid costly modification on the plant structure. The interest of industry in this field is acknowledged by the fact that Amazon a few years ago promoted the Amazon Picking Challenge [4]. In this occasion international teams competed in the challenge of picking different items from shelves, with their manipulators. Other important results in the field of constrained manipulation for logistics have been obtained within the European projects, such as ILIAD and REFILL projects, which respectively propose autonomous depalletizing for alimentary goods with a fixed bimanual robotic system [9], and solution for single arm object manipulation within shelves of a supermarket [5].

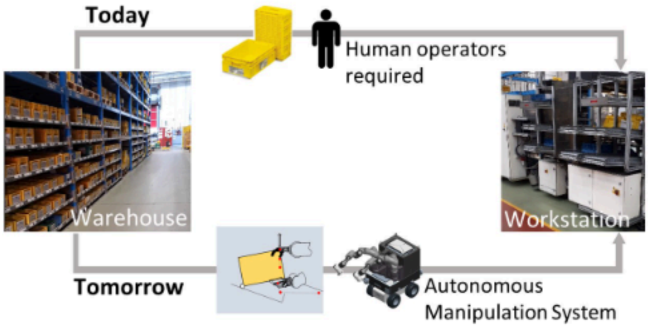

Fig. 1: Abstraction of our idea of autonomous logistics. Currently the transport of material form the warehouse to the workstation is performed manually, we aim at the full automation of the process.

In this work we consider a real industrial use-case related to the transport of boxes from a warehouse where the material is stored to workstations where the material is processed. We consider both of navigation and constrained object manipulation, performed with a mobile bimanual robotic system.

This work was carried on within the JOiiNT LAB[1], which is a joint laboratory established between IIT[2] and Consorzio Intellimech[3], dedicated to applied research and technological transfer. Two companies, Brembo S.p.A. and SAME Deutz-Fahr S.p.A., collaborated to the definition of the case-study and to the technical development

In the following we present description of our framework for autonomous logistics and some preliminary results.

II. CASE STUDY

The development of our autonomous framework for logistic operations refers to an industrial site, where the plant logistics are currently performed by human workers. Boxes of two different sizes and variable weight are moved from a warehouse

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[1] https://www.joiintlab.com/
[2] https://www.iit.it/
[3] https://www.intellimech.it/

to the production area. Those environments are characterized by rigid structures that create constraints for the gather and deposit of the boxes. Each time a workstation needs a refill of material, the human operator is required to complete the following tasks: first reach the location in the warehouse where the material is placed, then recognize among the boxes in the warehouse the correct one, using for this purpose a dedicated labeling. Then manipulate the box in order to extract it from the warehouse's shelf, deposit the box on a support and use the support to move the box to the workstation. Finally pick the box from the support, recognize a suitable incline roller on the machine and deposit the box on it.

III. AUTONOMOUS FRAMEWORK

To realize the boxes flow the robot would require skills of

- **Manipulation:** to grasp and handle objects in constrained environments.
- **Navigation:** to move from one position to another, with active obstacle detection and avoidance.
- **Perception:** to get key information about the surrounding environment.

The manipulation skill is the one that presents the most challenges, related to planning and environment interaction. Fig. 2 shows the structure of our framework for constrained manipulation for the plant logistics application, which build on the research and approaches developed within [9].

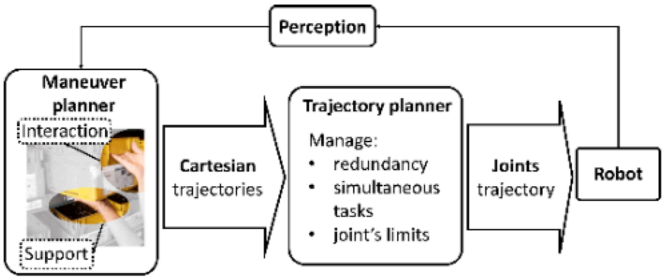


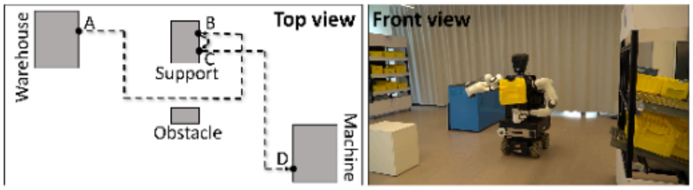
Fig. 2: Description of the framework for autonomous manipulation.

To achieve an efficient manipulation capability for the task in consideration we defined grasping and handling strategies inspired by the human behavior. For the boxes case, during the manual operation, we observed that each hand has a specific role of support, and one of interaction with the object.

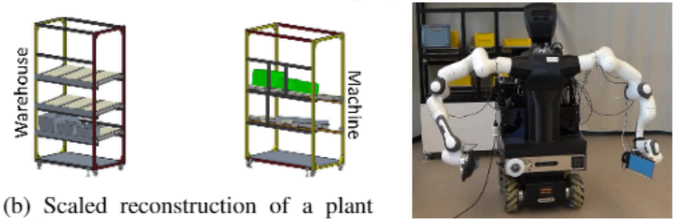
Our autonomous framework is based on a maneuver planner block which collects the set of manipulation strategies associated to each object type, and determines the reference cartesian trajectories for the robot. Those trajectories are scalable depending on the relative position between the robot and the environment, where the latter is identified through the perception system. We referred to [7] and [12] for the planning of joint trajectories while taking into account the multi-body structure and redundancy of the robot, the constraints on joints position, speed and acceleration, and the constraints on the robot operational workspace. Since the application is characterized by a constrained environment with various source of uncertainties (such as the dual arm grasp internal forces, errors from the vision system, mobile base path tracking error) we choose to introduce some robotic softness [2], both at the arm level [8] and at the gripper level [6]. This increases the adaptability of the robot in the interaction with the environment, making it more robust with respect to collisions and positioning errors. Currently we use cameras and QR code recognition for the perception of the surrounding environment, nonetheless other sensors could easily added in the framework. For navigation we refer to state of the art algorithms [13].

IV. TESTING SETUP AND PRELIMINARY RESULTS

We performed the testing of the autonomous framework on a scaled reconstruction of the plant environment (see Fig. 3b), with JOiiNT LAB's robot (see Fig. 3c), which is a bimanual anthropomorphic robotic system mounted on an onmidirectional mobile base, sensorized with cameras and lidar sensors. The two manipulators perform the roles of interaction and support in the box manipulation strategies. The grippers are respectively a Pisa/IIT SoftHand [3], which is characterized by robustness and adaptability, and a Velvet gripper [11], which has the capability to pull and push the object through a conveyor belt. The presence of the mobile base allows for navigation and introduces additional degrees of freedom during manipulation. The sensors are necessary for planning and obstacle avoidance. Although we test the application on a single robotic platform, the autonomous framework is scalable on different models of manipulators, mobile base, grippers and sensors. Fig. 3a shows the testing layout: the robot is requested to pick a box from a warehouse at point A, deposit it on a support at point B, then to pick box of different size form the support at point C and deposit it to the machine tending at point D. Fig. 4 shows a photo sequence of the robot moving from C to D.



(a) Testing layout



(b) Scaled reconstruction of a plant environment.

(c) JOiiNT LAB robot.

Fig. 3: Images from the JOiiNT LAB set up, for the demonstration of autonomous logistics application.

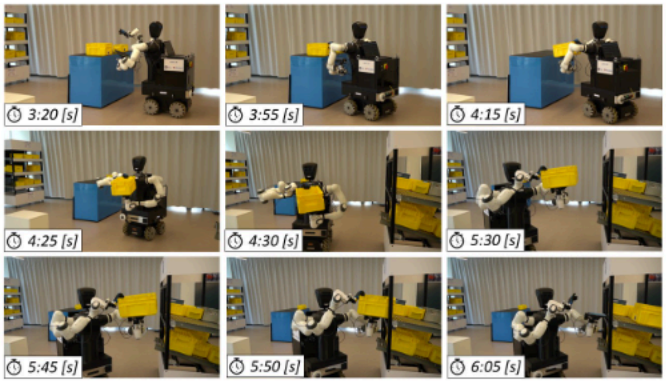


Fig. 4: Testing of the autonomous framework for logistics. Reading from left to right, up to down, we report a photo sequence of the box picking from the support, followed by the robot autonomous navigation and box deposit on the machine side.

At the current stage the robot completes the whole activity in about 7 $[min]$. As described in Fig. 5 about 40% of the time is dedicated to the physical execution of the manipulation and navigation tasks and 5% to acquire and elaborate camera's images. The remaining duration is 20% to plan the joints trajectory and 35% is occupied by interrupts to allow process monitoring. The overall duration has room for improvements, especially on the last two items.

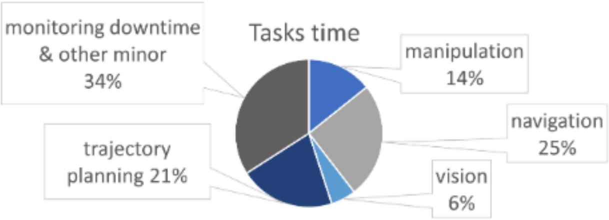


Fig. 5: Time occupancy of the phases of the autonomous execution during the demonstration.

V. CONCLUSION AND FUTURE WORKS

In this work we investigated the automation of the logistics process for a production plant. We developed solutions based on a real case-study, relying on the observation of an existing plant. At the current stage we are able to demonstrate full autonomy of the logistics process on a laboratory setup, integrating aspects of manipulation and navigation. Future works will consider more deeply the critical aspects for engineerization, such as the robustness and duration of the task, and testing on the field.

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REFERENCES

[1] Abdulrahman M. Basahel. Investigation of work-related musculoskeletal disorders (msds) in warehouse workers in saudi arabia. *Procedia Manufacturing*, 3:4643–4649, 2015. 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015.

[2] Antonio Bicchi and Giovanni Tonietti. Fast and soft arm tactics. *IEEE RA Magazine*, 11:22–33, 01 2004.

[3] M.G. Catalano, G. Grioli, E. Farnioli, A. Serio, C. Piazza, and A. Bicchi. Adaptive synergies for the design and control of the pisa/iit softhand. *The International Journal of Robotics Research*, 33(5):768–782, 2014.

[4] Nikolaus Correll, Kostas E. Bekris, Dmitry Berenson, Oliver Brock, Albert Causo, Kris Hauser, Kei Okada, Alberto Rodriguez, Joseph M. Romano, and Peter R. Wurman. Analysis and observations from the first amazon picking challenge. *IEEE Transactions on Automation Science and Engineering*, 15(1):172–188, 2018.

[5] Marco Costanzo, Giuseppe De Maria, Gaetano Lettera, and Ciro Natale. Can robots refill a supermarket shelf?: Motion planning and grasp control. *IEEE Robotics Automation Magazine*, 28(2):61–73, 2021.

[6] Clemens Eppner, Raphael Deimel, Jose Alvarez-Ruiz, Marianne Maertens, and Oliver Brock. Exploitation of environmental constraints in human and robotic grasping. *The International Journal of Robotics Research*, 34, 06 2015.

[7] Fabrizio Flacco and Alessandro De Luca. Unilateral constraints in the reverse priority redundancy resolution method. In *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, page 2564–2571. IEEE Press, 2015.

[8] Stefan Fuchs, Sami Haddadin, Maik Keller, Sven Parusel, Andreas Kolb, and Michael Suppa. Cooperative bin-picking with time-of-flight camera and impedance controlled dlr lightweight robot iii. In *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 4862–4867, 2010.

[9] Manolo Garabini, Danilo Caporale, Vinicio Tincani, Alessandro Palleschi, Chiara Gabellieri, Marco Gugliotta, Alessandro Settimi, Manuel Giuseppe Catalano, Giorgio Grioli, and Lucia Pallottino. Wrapp-up: A dual-arm robot for intralogistics. *IEEE Robotics and Automation Magazine*, 28(3):50–66, 2021.

[10] Shihua Li, Jing Yan, and Lingxi Li. Automated guided vehicle: the direction of intelligent logistics. In *2018 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI)*, pages 250–255, 2018.

[11] Vinicio Tincani, Manuel G. Catalano, Edoardo Farnioli, Manolo Garabini, Giorgio Grioli, Gualtiero Fantoni, and Antonio Bicchi. Velvet fingers: A dexterous gripper with active surfaces. In *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 1257–1263, 2012.

[12] Diederik Verscheure, Bram Demeulenaere, Jan Swevers, Joris De Schutter, and Moritz Diehl. Time-optimal path tracking for robots : a convex optimization approach. *IEEE Transactions on Automatic Control*, 54(10):2318–2327, 2009.

[13] Li Zhi and Mei Xuesong. Navigation and control system of mobile robot based on ros. In *2018 IEEE 3rd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC)*, pages 368–372, 2018.