Emerging Paradigms for Robotic Manipulation: From the Lab to the Productive World

By Maria Pozzi, Virginia Ruiz Garate, Arash Ajoudani, Kensuke Harada, Monica Malvezzi, Leonel Rozo, and Maximo A. Roa

Novel robotic developments are going hand in hand with the need for innovation in manufacturing and service applications. Large industries increasingly need fast-adapting production lines, whereas small and medium-sized enterprises are adopting collaborative manipulators to gain a competitive edge in global markets. Additionally, a growing number of companies are producing and using service robots for a variety of applications, from agriculture to surgery. In this emerging framework, robots should be able to grasp and manipulate different tools as well as operate in fast-changing or even unstructured surroundings, possibly interacting with human users or coworkers. These real-world scenarios require going beyond traditional parallel-jaw grippers and preprogrammed or teleoperated trajectories and require searching for innovative grasping and manipulation paradigms that can cope with the needs of uncertain environments. Proposed solutions include soft manipulation, data-driven grasp planning, and human–robot collaborative manipulation. But how long will it take to see these novelties outside of research labs?

For this quest to be successful, we cannot focus on solving only purely technological and application-driven issues; we need a holistic, interdisciplinary view of the robotic system. Basic research on single components (robotic grippers, sensing, and grasp control) and a deep understanding of the scenario(s) in which the robot will work are both fundamental to achieving the desired result. In this context, a tight collaboration among research scientists in different fields and final end users or producers of the technology is required.

This special issue aims to stimulate and gather publications describing how new approaches in the field of robotic manipulation can be (or have already been) transferred from research labs to the productive world. Nine articles have been included in this collection, and we briefly summarize them in the following.

Robotic hands and grippers represent the ultimate interface between robot arms and manipulated objects. Their design and control still pose important challenges to the research community, and there is a growing trend to embed part of the intelligence of the manipulation system directly into the hardware design of the end effector without demanding it completely from the robot software. For example, the use of compliant elements or soft materials ensures an intrinsically safe interaction with the environment as well as a passive shape adaptation between the gripper and the grasped object. The first three articles of the special issue focus on the development of new end effectors based on different design principles. Kim and Deshpande propose a method to optimize the nonlinear parallel compliance of a robotic gripper to meet stability goals and further reduce the overall stiffness of a device through a coupled tendon routing. McCann et al. present the design, modeling, dimensional synthesis, and experimental characterization of a robotic hand having a parallel structure inspired by the Stewart–Gough platform. Wang et al. describe the design and fabrication of a novel humanoid hand made of intrinsically soft materials and endowed with pneumatic fingers and a palm capable of adapting to several different grasped objects.

Alongside suitable end effectors that allow the physical handling of objects, deploying a manipulation system into a real-world scenario, it is fundamental to endow the system with proper sensing capabilities. Because tactile sensing requires direct contact between surfaces and due to the lack of a solid and robust tactile sensor that can resist everyday use, tactile sensing in industrial settings has so far been discouraged, and vision-based solutions are preferred. The research field of robotic vision has reached a high level of maturity, and its application to manipulation tasks has recently been expanded by the introduction of machine learning algorithms capable of identifying, localizing, and classifying objects based on large training data sets of images. In the article by Koskinopoulou et al., a deep-trained computer vision module for the categorization of recyclables is developed and integrated with a robotic manipulation system (a delta robot equipped with a blower-based vacuum gripper) for sorting recyclables in a material recovery facility.

Digital Object Identifier 10.1109/MRA.2021.3067685
Date of current version: 11 June 2021

In terms of manipulation planning and control, the hardest challenge is to enhance the robot's adaptation to variations coming from the environment in terms of the executed tasks, especially in situations involving the presence of humans. This typically translates into endowing a manipulator with multilevel technical capabilities. At a lower level, robots must be equipped with adaptive controllers that can respond to the uncertainties arising from planning and control. At a higher level, the coordination of multiple agents (humans and robots) toward achieving a target goal becomes crucial. The work by Costanzo et al. tackles the challenges related to motion planning and grasp control in a complex manipulation task such as replenishing a supermarket shelf. For manipulating single and diverse products in narrow spaces, the authors propose reactive control strategies based on physics models and tactile and visual perception. Experiments in a relevant environment emulating a real supermarket shelf are carried out. The article by Logothetis et al., in contrast, provides a good example of the efficient supervision and coordination of a heterogeneous system through a decentralized framework that integrates high-level task planning; low-level motion planning and control; and robust, real-time sensing of the environment. The authors validate this approach in a multitasking collaboration scenario involving various robots and humans.

The proficient and robust integration of novel devices and methodologies into complex manipulation systems requires adequate methods and experimental setups to allow consistent evaluation and testing. The article by Triantafyllou et al. moves in this direction by proposing a novel software methodology to assess the effort and impact of integrating a robotic component into a more complex system. The described method is demonstrated in an industrial tool-packing task performed with a dual-arm manipulator. In addition, the work presented by Denoun et al. aims to facilitate the integration and testing of the hardware and software components of a manipulation system. In particular, the authors introduce a robot-agnostic software framework that enables visual programming and fast prototyping of robotic grasping and manipulation tasks.

Answering to the need for a comprehensive evaluation of robotic systems, robotic competitions and challenges are gaining a major role in the benchmarking of manipulation platforms as they offer a valuable occasion for assessing, testing, and comparing systems in common and standardized tasks. Roa et al. present the results of the 2018 Mobile Manipulation Hackathon, where the Take It and Go (TIAGo) platform was used to showcase the latest applications of wheeled robotic manipulators competing to perform a series of real-world tasks. In this article, the authors analyze and discuss the main challenges found in the several components needed for a successful mobile manipulation, the advancements made since the competition took place, and areas of potential development in expanding the applications of mobile manipulators in productive environments.

The articles collected in this special issue not only introduce novel devices and concepts but also demonstrate how new grasping and manipulation paradigms can be transferred from the lab to real-world applications, ranging from recyclables sorting and human–robot collaboration in warehouses to filling supermarket shelves. Since many of the articles are coauthored by representatives of companies and of research institutions, they can also inspire experts in other research areas by showing good examples of collaborations between academia and industry.