Robotic Hands, Grasping, and Manipulation

By Matteo Bianchi, Jeannette Bohg, Hyungpil Moon, Robert Platt, and Rich Walker

The design of robotic hands and grippers and the study of robotic grasping and manipulation represent key research areas in robotics. In the last decade, attention to these topics has significantly increased. According to Scopus, for the period 2015–2019, the number of publications with keywords related to "grasping," "manipulation," and "robot hand" in the subject areas of engineering and computer science has grown by more than 50%. We see two key reasons for this trend.

On the one hand, robot technologies for industrial use have matured. The need for robotic systems that can perform vastly different grasping and manipulation tasks in unstructured environments has guided research on robotic hardware and tactile sensing, leading to the development of more robust, adaptable, and sensitive robotic arms and hands. Following the human example, a key enabler of robust robotic manipulation is the ability to exploit the environment and cope with uncertainty in perception and dynamics during physical interaction. On the other hand, deep learning techniques and an increase in computational power provided new opportunities for planning and controlling robotic grasping and manipulation in complex and varying scenarios where the robot may only receive partial information through noisy sensors. These research developments in both hardware and software hinge on the cross-fertilization among different areas of investigation, such as neuroscience, robotics, engineering, and computer science as well as between academia and industry.

To foster the exchange of ideas in this field, the IEEE Robotics and Automation Society (RAS) Technical Committee (TC) on Robotic Hands, Grasping, and Manipulation was established in 2014. The main organizational structure consists of five cochairs, four from academia (Matteo Bianchi, University of Pisa; Jeannette Bohg, Stanford University; Hyungpil Moon, SungKyunKwan University; Robert Platt, Northeastern University) and one from industry (Rich Walker, managing director of the Shadow Robot Company as well as an industry director of EuRobotics), who helps to build links to the European robotics industry. The cochairs also appointed two Distinguished Lecturers, Ji-Hun Bae (Korea Institute of Industrial Technology) and Marc Toussaint (Technical University of Berlin).

TC Activities

Since 2014, our TC has gained more than 191 members, with 25.1% joining in their capacity as industry representatives (status April 2021), all of whom are informed about TC activities through a dedicated mailing list. Figure 1 illustrates membership statistics. The TC has offered continuous support to the organization of workshops at main conferences (for example, 18 in the main international robotics conferences for the period 2015–2018). The TC has also taken its lead from the IEEE Diversity Statement (https://www.ieee.org/about/diversity.html) and strives to ensure equitable balances across both speakers and organizers of workshops.

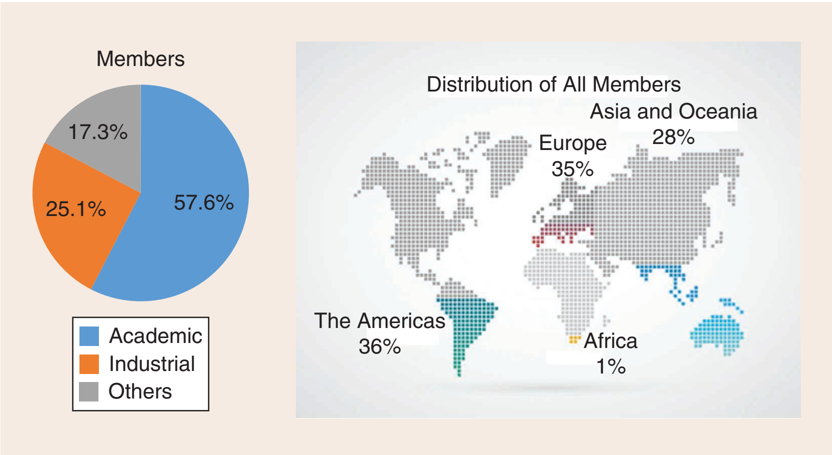

Figure 1. Membership statistics.

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In addition, the TC has supported summer schools, special issues, and competitions for benchmarking. For example, the Robot Grasping and Manipulation Competition was established during the 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems. The competition provides a common set of robotic manipulation tasks to benchmark hand designs as well as autonomous grasping and manipulation solutions. Another interesting competition is the Amazon Picking Challenge (2015–2017), which was designed to address a gap in the automated warehousing processes of Amazon. The competition was held for the first time during the 2015 IEEE International Conference on Robotics and Automation with the successful participation of international teams from academia and research institutions. Among the various educational activities promoted by the TC is the first international IEEE RAS Summer School on Soft Manipulation, which showcased the key principles of developing simple, compliant, yet strong, robust, and easy-to-program manipulation systems.

Furthermore, in the last years, several TC members have contributed to spread awareness of TC activities outside the RAS, for example, giving invited talks at nonrobotics conferences such as the Conference on Computer Vision and Pattern Recognition and the Conference on Neural Information Processing Systems as well as participating in general public events such as Maker Faire (European Edition, Rome 2017), TEDx talks (TEDxRoma, 2016), events with entrepreneurs and industry representatives (such as Automatica in Munich, Germany, the leading exhibition for robotics and automation, in 2016 and 2018), and international political events (fifth Workshop of the Council of the United States and Italy, 2015). This is a nonnegligible signal on how the growth of the TC committee can provide tangible results for cross-fertilization between academia and the industrial world, which we will push further in the coming years.

Challenges and Future Directions

In recent years, the international community on robotic hands, grasping, and manipulation has made important progress toward research frontiers, including the following:

1) The design and control of soft yet robust robotic hands that can adapt and interact with the environment to enrich their grasping capabilities have been pushed significantly further. Scientific interest on this topic has led to the establishment of a new multidisciplinary field—that is, soft manipulation that combines material science, different actuation principles, hardware design, planning, and control. Soft manipulation ideas have also been successfully combined with the principled simplification approach of hand synergies—that is, dimensionality reduction in human hand control space, producing interesting examples of deformable, underactuated robotic hands. This simplification, adaptability, and robustness has also opened promising scenarios for the development of easy-to-control soft hand prostheses with a potentially high impact on assistive robotics and in amputees' daily life. This impact can be further amplified by the open access approach for data and design component information sharing (see, for example, the Natural Machine Motion initiative; HandCorpus, an open access repository for sharing data; and Open Bionics, an open-source initiative focusing on adaptive robotic and bionic devices that can be easily reproduced using off-the-shelf materials) promoted by our TC, which is contributing to build an example of such a task an international and multidisciplinary community of researchers interested in hands, grasping, and manipulation.
2) Combined task and motion planning is concerned with simultaneously finding appropriate motion trajectories and a sequence of high-level manipulation actions to achieve complex tasks that require long-horizon reasoning. Figure 2 shows an example of such a task (Tower of Hanoi), where the robot must find not only an appropriate sequence of high-level pick-and-place actions but also the low-level continuously valued motion trajectories to execute this sequence. Paralleling the innovations in sensorimotor control for robotic manipulation through machine learning [see 3) following], combined task and motion planning has received considerable attention during the last years, proposing new

Figure 2. A robot using task and motion planning to solve the Tower of Hanoi puzzle. The robot consists of a Franka Panda arm and a Robotiq Gripper.

optimization approaches for enabling robots to use tools and perform complex tasks as, for example, showcased by Marc Toussaint [1], the TC's Distinguished Lecturer.

3) In terms of deep learning and big data, interest in applications of machine learning to robotic grasping and manipulation has increased significantly. One of the most visible examples of this was Google's arm farm, which learned grasp strategies from experience gained across a "farm" of 14 robotic arms operating in parallel continuously over a period of months [2], [3]. Another prominent example is the Learning Dexterity project by OpenAI [4], where the authors use reinforcement learning to train a Shadow Dexterous Hand in simulation and demonstrate that the same policy can manipulate objects on the real platform as well. These two examples illustrate the important connection between deep learning and big data: deep learning is powerful but must be fueled by significant amounts of training data. To facilitate learning about the specific challenges of applying machine learning to robotics, a crowdsourced list of the most important research articles in the field of robot learning was created: robotlearninglist.com. While this list is not focused on grasping and manipulation, it contains very important references related to this specific subarea as well.

Some of these ideas have not yet had a significant impact on industry: the next steps could envision a more in-depth involvement of industrial companies on robotic manipulation and a scientific effort to integrate robotic design and control with machine learning tools, promoting a codesign approach. This should also include consideration of recent advances in tactile sensing, especially in soft optics-based tactile sensors such as GelSight [5], which can be integrated in robotic manipulators to increase their sensorimotor skills.

References

[1] M. Toussaint, K. Allen, K. Smith, and J. Tenenbaum, "Differentiable physics and stable modes for tool-use and manipulation planning," *Robot., Sci. Syst.*, June 2018.

[2] S. Levine, P. Pastor, A. Krizhevsky, J. Ibarz, and D. Quillen, "Learning hand-eye coordination for robotic grasping with deep learning and large-scale data collection," *Int. J. Robot. Res.*, vol. 37, nos. 4–5, pp. 421–436, 2018. doi: 10.1177/0278364917710318.

[3] D Kalashnikov et al., "Scalable deep reinforcement learning for vision-based robotic manipulation," in *Proc. 2nd Conf. Robot Learn. (PMLR),* 2018, vol. 87, pp. 651–673.

[4] O. M. Andrychowicz et al., "Learning dexterous in-hand manipulation," *Int. J. Robot. Res.*, vol. 39, no. 1, pp. 3–20, 2020. doi: 10.1177/0278364919887447.

[5] W. Yuan, S. Dong, and E. H. Adelson, "GelSight: High-resolution robot tactile sensors for estimating geometry and force," *Sensors*, vol. 17, no. 12, p. 2762, 2017. doi: 10.3390/s17122762.

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