Collaborative Robots in the Workplace

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According to the latest report from the International Federation of Robotics, 2016 saw the highest number of industrial robots installed worldwide, nearly 300,000 units. Despite this constant sales growth, industrial manipulators are mainly used only in traditional markets such as automotive and electronics. The sizable investment required to acquire, install, commission, and train industrial robots still deters small- and medium-sized companies from implementing this technology. The limited flexibility of such platforms remains the most critical entry barrier for potential users to adopt robotized solutions.

In response to the increasing demand for the mass customization of products in the global marketplace, a completely new class of robots has recently appeared, representing an affordable solution to this problem. Designed to safely collaborate with human workers, these robots are presenting new opportunities to partially automate manufacturing processes. Previously, the use of automation and robotics has been an all-or-nothing proposition. For these reasons, the field of collaborative robotics is quickly expanding its range of applications: according to a recently published market forecast from Loop Ventures, by the year 2025, one in three robots will be used for collaborative applications. Recent statistics also indicate that the corresponding market is expected to expand at a compound annual growth rate of nearly 60%, reaching US$12 billion within the next ten years. As with traditional robots of more than 40 years ago, the early adopters for this technology have been automobile manufacturers. However, while it took more than 40 years for traditional robots to be adopted in significant numbers outside the automotive sector, collaborative robotics has already penetrated other industries since their first appearance in the marketplace.

Motivated by the increasing demand for flexibility and reconfigurability in modern production environments, the main focus of this June 2018 special issue of *IEEE Robotics and Automation Magazine* is to provide a snapshot of the most advanced applications of human–robot collaboration in relevant environments. The benefits of workspace sharing have already demonstrated the potential for humans and machines to assist one another with complementary skills. Although the social implications of a massive adoption of automation with respect to the loss of manufacturing jobs is still hotly debated, it is widely recognized that a hybrid manufacturing environment can significantly reduce the risk of work-related musculoskeletal injuries. Mobile manipulators, wearable augmented devices, and collaborative robots are a few examples of how humans and machines can mutually benefit one another.

The issue features nine articles selected by guest editors as part of a two-round review process. The result is an incredible variety of technologies and applications, highlighting the broad interest in collaborative robotics for academics and the general industry.

The question of which tasks are suitable for automation to boost productivity and relieve human operators from performing repetitive tasks is a natural consideration. Once a task has been identified, the real issue is how to set up a robotized station to perform the job. The first article addresses this subject by proposing a framework that optimizes the kinematic structure of modular robots programmed by human demonstrations.

In physical human–robot interactions (pHRIs), how to demonstrate and transfer a skill from human experts to robots is of great importance. The authors of the second article propose a passive mechanism of macro–mini architecture. The mini low-impedance passive mechanism allows users to intuitively demonstrate the task at hand, while the high-impedance active system can be driven effectively to accomplish the desired tasks. This structure is especially useful for manufacturing applications in which both safety and demonstration efficiency should be taken into account.

When humans start to interact with robots physically, safety becomes one of the most important factors. Although pHRI has been thoroughly investigated, how to measure and modulate the safety features is still an open question. In the third article, an open-source software, OpenPHRI, is developed to

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measure and adjust the safety features at both the joint and task level.

In the fourth article, the ClaXon project builds on insights from previously studied HRI challenges and moves from laboratory experiments to a case study of collaborative robotics in a realistic industrial setting. As such, this documented acceptance of a robotic coworker in an Audi factory is an important milestone for the community.

The fifth article presents an approach for developing a shared understanding of tasks and goals within a human–robot team working on a collaborative manufacturing task. Visual cues enhance the efficiency and the effectiveness of the team and improve the user's satisfaction when collaborating with the robot.

Historically, the automotive industry has always been an early adopter of robotic technologies. Therefore, it should not be surprising that car assembly still represents a natural test bench for new trends in collaborative automation. The sixth article describes every phase, from design to deployment of a mobile robotic assistant capable of working alongside humans on moving-floor automotive assembly lines.

Aside from factories, the building construction industry is another market open for a robotic takeover. According to the U.S. Bureau of Labor Statistics, nearly 200,000 construction jobs were left unfilled in 2017. In the seventh article, a cooperative painting robot that performs interior finishing on high walls is developed. The robot works collaboratively with human workers, with the worker's judgment and perception serving as the upper robot planner; the robot adjusts the painting plans autonomously from various deployed positions.

Ease of programming and reusability of software are clearly not the sole assets of collaborative robotics. Heavy industries are also interested in mitigating the risk of musculoskeletal disorders, which represent at least 45% of work-related diseases, according to the European Agency for Safety and Health at Work. For these reasons, the eighth article presents a lower-back exoskeleton powered by series elastic actuators to support industrial workers handling heavy materials.

Our final article introduces an innovative smart companion robot for automotive assembly that combines a 3-RPS parallel mechanism on top of a mobile robot equipped with omniwheel. Unlike its predecessors, this robot can act autonomously over a large working area, actively assisting human workers in transporting and manipulating relatively heavy automotive parts and subassemblies.

This special issue of *IEEE Robotics and Automation Magazine* covers most of the technologies and numerous applications of collaborative robotics. The collaborative era has truly begun. While researchers are already working hard in their labs to solve the next challenges, the articles herein provide a snapshot of this bourgeoning technology. Enjoy the special issue!