Robotics and Computer–Integrated Manufacturing 71 (2021) 102162

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

Editorial

Agile robotics for industrial applications: Editorial

Advances in automation have provided for sustained productivity increases and manufacturing growth over the past decade. Sustaining this growth will require automation to become more agile and flexible, enabling the automation of tasks that require a high degree of human dexterity and the ability to react to unforeseen circumstances. Applying robots is one promising approach, but their traditional program-by-teaching model takes considerable time, requires extensive expertise, and does not lend itself to tasks that require adaptability. This has limited robots to high-volume, repetitive operations and precluded them from low-volume, time critical, and flexible projects. Off-line programming of robots is possible, similar to the computer-aided manufacturing (CAM) method widely used for machine tools. However, the poor accuracy of robots compared with machine tools limits them to jobs with low tolerance requirements, or requires additional methods such as calibration, modeling, and external sensing to improve their accuracy. These methods increase the upfront cost of a robotic system. However, advances and cost reduction in sensing technologies (especially laser scanning) have brought robot systems into the price range of even small-to-medium enterprises. In addition, use of end-of-arm tools (EOAT) has given integrators the ability to provide faster turnaround time and utilize the same infrastructure in a high-mix, low-volume environment.

This special issue addresses approaches that will allow robotic systems of tomorrow to be capable and flexible. This includes approaches that will allow robots to be quickly re-tasked to other operations, and cope with a wide variety of unexpected environmental and operational changes. For the purpose of this special issue, we refer to this as agility. Key areas of robot agility include:

(1) The ability of a robot to be rapidly re-tasked without the need to shut down the robot for an extended period when a new operation needs to be performed,
(2) The ability of a robot to recover from errors, so that when a part is dropped, for example, the robot can assess the situation and determine the best way to proceed to accomplish the goal,
(3) The ability to quickly swap in and out robots from different manufacturers so that a company is not tied to a single robot brand,
(4) The ability for a robot to respond to changing environmental conditions, for example, when a part is not in the precise location the robot anticipated.

Nine papers were accepted to this special issue. Their titles and descriptions are listed below, clustered by appropriate focus area:

- Robot Commissioning and Production Planning
  - “Generic development methodology for flexible robotic pick-and-place workcells based on Digital Twins” proposes a generalized development methodology for flexible robotic pick-and-place workcells, in order to provide guidance and thus facilitate the development process. The methodology is based on the Digital Twin (DT) concept, which allows the iterative refinement of the workcell both in the digital and in the physical space. The goal is to speed up the overall commissioning (or reconfiguration) process and reduce the amount of work in the physical workcell.
  - “Spillover Algorithm: A Decentralized Coordination Approach for Multi-Robot Production Planning in Open Shared Factories’’ describes an (intrinsically decentralized) shared factory scenario. The scenario requires decentralized methods for efficient allocation of robots (production resources) of the same shared manufacturing plant to individually rational and self-concerned firms (users) that use them to manufacture their products in a given time horizon. The authors propose a computationally efficient decentralized approach based on the spillover effect that solves this nondeterministic polynomial time (NP)-hard problem by distributing decisions in an intrinsically decentralized multi-agent system environment while protecting private and sensitive information.
- Robot control and path following
  - “Safe and intuitive manual guidance of an industrial robot using adaptive admittance control” focuses on methods that increase capability and flexibility of industrial robots and facilitate robot re-tasking. It claims that manual guidance can achieve robot agility effectively, provided that a safe and smooth interaction is guaranteed when the user exerts an external force on the end effector. The authors approach this by designing an adaptive admittance law that can adjust its parameters to modify the robot compliance in critical areas of the workspace, such as near and on configuration singularities, joint limits, and workspace limits, for a smooth and safe operation.
  - “A Visual Path-following Learning Approach for Industrial Robots using DRL” proposes using a Deep Reinforcement Learning (DRL) approach to solve path following tasks using a simplified virtual environment with domain randomization to provide the agent with enough exploration and observation variability during the training to generate useful policies to be transferred to an industrial robot.
- Human-Robot Interaction
  - “Improving human robot collaboration through Force/Torque based learning for object manipulation” describes a learning from demonstration methodology that combines an ensemble machine

https://doi.org/10.1016/j.rcim.2021.102162

Available online 24 March 2021
0736-5845/Published by Elsevier Ltd.

learning algorithm (i.e. Random Forest (RF)) with stochastic regression, using haptic information captured from human demonstration. The proposed method is shown to be capable of imitation learning; interpreting human actions and producing equivalent robot motion across a diverse range of initial and final conditions.
    - "A novel robot co-worker system for paint factories without the need of existing robotic infrastructure" presents a human-robot co-working system to be applied to industrial tasks such as the production line of a paint factory. The aim is to optimize the picking task with respect to manual operation.
- Experiences with The Agile Robotics for Industrial Automation Competition (ARIAC)
    - "Assessing Industrial Robot Agility Through International Competition" describes the process for creating and the lessons learned over multiple years of the ARIAC Competition being run by the National Institute of Standards and Technology (NIST).
    - "Winning ARIAC 2020 by KISSing The BEAR: Keeping Things Simple in Best Effort Agile Robotics" discusses the authors' evolved understanding on the meaning of agile robotics. The lessons learned are concluded from the four years of their participation in ARIAC, that the authors managed to win in 2020. After elaborating on ARIAC tasks, challenges and scoring and their consequences on algorithm design, error handling and software development processes and methodologies, they introduce the concept of Best Effort Agile Robotics (BEAR).
    - "Team RuBot's Experiences and Lessons from the ARIAC '' shares experiences and lessons learned by the Rutgers University team in participating in the annual ARIAC Competition.

The authors are hoping that this special issue will help to show the importance of agility in robotics systems. While the articles in this special issue show that good work has already begun, there is much more needed. We hope that this special issue shows researchers that there are many more opportunities for them to develop techniques to enhance the agility of robots, and for industry to begin utilizing robot agility approaches more exhaustively.

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