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Editorial

Editorial of the Special Issue "Advanced Robotics Applications in Industry"

Nikolaos Papakostas [1,*], Lihui Wang [2,*], Sotiris Makris [3,*] and Dimitris Mourtzis [3,*]

1 Laboratory for Advanced Manufacturing Simulation and Robotics (LAMS), School of Mechanical and Materials Engineering, University College Dublin, D04 V1W8 Dublin, Ireland
2 Department of Production Engineering, KTH Royal Institute of Technology, 10044 Stockholm, Sweden
3 Laboratory for Manufacturing Systems and Automation (LMS), Department of Mechanical Engineering and Aeronautics, University of Patras, 26504 Rio Patras, Greece
* Correspondence: nikolaos.papakostas@ucd.ie (N.P.); lihuiw@kth.se (L.W.); makris@lms.mech.upatras.gr (S.M.); mourtzis@lms.mech.upatras.gr (D.M.)

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1. Special Issue Summary

Recently, the emergence of various technological advancements has enabled the development of new and unique applications for industrial robots. The establishment of sensing, perception, machine intelligence, control, and computing paradigms has provided a solid foundation for the introduction of innovative robotic-related technologies in a wide range of diverse fields and manufacturing sectors.

Consequently, there is a need for further research initiatives to demonstrate the incorporation of robots in a more extensive array of processes and applications, including those that require close collaboration with human operators. Additionally, there is a need to achieve a higher degree of flexibility while simultaneously promoting faster and more precise modeling, simulation, and control of industrial robotics processes using Industry 4.0 technologies.

2. Summary of the Special Issue Research Works

The Special Issue consists of seven (7) research works, among which six (6) are original research articles and one (1) is a literature review manuscript. in the following paragraphs, a short summary of each manuscript is presented.

In the first paper, presented by Kuo and Pongpanyaporn [1] a tracking control strategy is proposed for nonlinear systems based on the utilization of a combination of continuous-time model predictive control and feedback linearization. While similar combinations have been presented in the literature, they often involve complex formulations and significant computations. Therefore, the key innovation of this study lies in the simplification of the formulation process and the reduction of the computational load by using Laguerre functions for the approximation of the control signals. Furthermore, the paper also summarizes common linearization schemes, and the authors performed a comparison of the above-mentioned, highlighting their advantages and disadvantages. The effectiveness of the proposed approach is tested through two illustrative examples, and its performance is compared to those obtained from linear control strategies combined and other similar linearization schemes.

In the second paper, Mourtzis, Angelopoulos and Panopoulos [2] have focused on the design and development of a method for enabling remote robot control based on the implementation of Mixed Reality functionalities. Considering the introduction of collaborative manufacturing cells in the Industry 4.0 era, flawless communication between human operators and robotic manipulators for ensuring human safety and smooth collaboration is imperative. As a result, engineers have turned their attention to developing suitable human-robot interfaces (HRI) to address this issue. This research proposes a closed-loop framework for the HRI, utilizing digital technologies such as Mixed Reality (MR). Specifically, the framework can be implemented as a methodology for the remote and safe manipulation of the robotic arm in near real-time while simultaneously displaying safety zones in the field of view of the shop-floor technician. The approach is based on creating a Digital Twin of the robotic arm and establishing a suitable communication framework for continuous and seamless communication between the user interface, the physical robot, and the Digital Twin. The development of the method involves using ROS (Robot Operating System) for Digital Twin modeling, a Cloud database for data handling, and Mixed Reality (MR) for the Human-Machine Interface (HMI). The MR application developed is tested in a laboratory-based machine shop that incorporates collaborative cells.

Pu et al. in [3] proposed a modified cubic Hermite interpolation for joint motion planning in order to address issues related to point-to-point joint motion planning of industrial robots with constrained velocity, in which cubic polynomial planning exhibits discontinuous acceleration, while quintic polynomial planning requires pre-specified acceleration may lead to significant velocity fluctuations. The proposed methodology involves reconfiguring knots of the cubic Hermite interpolation according to the initial knots, and the formulas for building new knots are derived. Using the newly built knots in place of the initial knots for cubic Hermite interpolation, joint motion planning is conducted to ensure C^2 continuity and minimize velocity fluctuations while meeting the displacement and velocity constraints at the initial knots. For the validation of the proposed method, a case study is presented, which proves that the presented approach can effectively resolve the issues associated with the other two planning methods. With the implementation of this methodology, the improvement of the working performance and service life of industrial robots is expected.

In the fourth paper of the SI, Karagiannis et al. [4] presented a robotic cell that is capable of handling geometrically complex products by utilizing cognitive control and actuation systems for manipulation, assembly, and packaging. In order to achieve this, the mechatronic components, including a 6-degree-of-freedom (DoF) gripper and a flexible assembly mechanism, were designed through functional decomposition of the handling and assembly tasks. The flexibility of these mechanisms is leveraged through control modules which are capable of performing a wide variety of cognitive functions at the cell, resource, and device levels. The applied design approach can be applied to several tasks requiring dexterity and adaptation to different product types. A case study from the consumer goods industry is presented to demonstrate the reconfigurability and efficiency of the system.

In the context of robotic flexibility in industry, particularly with the emergence of the Industry 4.0 concept, Bavelos et al. in [5], have proposed a framework for smart execution control, aimed at facilitating the independent operation of flexible mobile robots in a manufacturing environment. These robots are capable of navigating the shopfloor independently and performing multiple tasks, while also serving as assistants to human operators. In order to facilitate such autonomous functionalities, the framework incorporates robot perception functions, which provide a real-time understanding of the shopfloor and the manufacturing process, while also coordinating the execution of tasks. A Digital World Model is deployed to combine sensor data from various 2D, and 3D sensors installed throughout the shopfloor. This model is used by the perception functions for enabling real-time perception of the shopfloor and manufacturing process by the robots. The effectiveness of this smart control system has been verified through a case study in the automotive industry.

Peng et al. in [6] introduced a robotic assembly method designed specifically for the production of large segmented composite structures. The methodology tackles three essential stages in the assembly process, in particular (i) panel localization and pick-up, (ii) panel transport, and (iii) panel placement. The proposed approach is based on the utilization of several stationary and robot-mounted cameras in order to provide information for the processes of part localization and alignment. Furthermore, a force/torque sensor mounted on the robot end effector enables secure and gentle panel pick-up and placement of the composite parts. Human-assisted path planning is utilized to ensure collision-free motion of the robot with a heavy load in tight spaces. The process flow and user interface are governed by a finite state machine which allows for process interruption and the return to the previous known state in case of error conditions or when secondary operations are needed. For the validation of the proposed method, a high-resolution motion capture system is used in order to set a reference for the ground truth. An experimental testbed integrating an industrial robot, vision, and force sensors, and representative laminated composite panels was developed to demonstrate the feasibility of the proposed assembly process. Experimental results have indicated that sub-millimeter placement accuracy with shorter cycle times, lower contact force, and reduced panel oscillation than manual operations is feasible. This work exemplifies the adaptability of sensor-guided robotic assembly operation in complex end-to-end tasks using the open-source Robot Operating System (ROS) software framework.

Finally, the literature review presented in [7] by Ramasubramanian et al. emphasizes flexible automation and customized product manufacturing using technologies such as the Internet of Things (IoT) and cyber-physical systems (CPS). The literature review expands also on the most pertinent developments in the field of digital twins. Digital twins are expected to play a crucial role throughout the product lifecycle as the manufacturing sector increasingly adopts digitized products, processes, and services. Furthermore, collaborative robots are being introduced into the shop floor to assist human operators in task completion through human-robot collaboration. This paper provides insights into the creation of digital twins for human-robot collaboration and the challenges involved. Among the key contributions of this research work is the examination of different approaches for the creation of digital twins, the discussion of the function and importance of digital twins in human-robot collaboration scenarios and highlighting of the challenges associated with creating digital twins, such as modeling the digital twin of human-robot collaboration and ensuring its exactness with respect to the physical system.

3. Concluding Remarks & Outlook

In this SI seven (7) research works have been published, focusing on the latest advances in the field of industrial robotics.

Despite the publication of the above-mentioned manuscripts, the corresponding works will be subject to further development, so that open challenges derived from the field can be adequately addressed. Following the literature investigation performed by the authors in [7] as well as from the rest of the research works [1–6], the recent Industry 4.0 technological advances have facilitated engineers to solve complex problems. however, new challenges are also emerging. Therefore, the research works presented as part of this SI might facilitate the global community since they lay the foundations for greater and more impactful advances, with the provision of insightful inspiration and applied frameworks and technologies.

Conflicts of Interest: The authors declare no conflict of interest.

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