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Editorial

Editorial of the Special Issue "Advances in Artificial Intelligence Methods Applications in Industrial Control Systems"

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1. Motivation for the Special Issue

Today, Artificial Intelligence (AI) applications are considered to be of increasing relevance for the future of industrial control systems [1–3]. AI methods are increasingly being applied at different industrial control systems levels, from single automation devices up to the real-time control of complex machines, production processes and overall factories supervision and optimization.

AI solutions are exploited with reference to different industrial control applications, from sensor fusion methods to novel model predictive control techniques, from self-optimizing machines to collaborative robots, and from factory adaptive automation systems to production supervisory control systems [1,4–13].

The motivation for the present Special Issue is to provide an overview of novel applications of AI methods to industrial control systems by means of selected best practices, to highlight how such methodologies can be used to improve the production systems self-learning capacities, their overall performance, the related process and product quality, the optimal use of resources and the industrial systems safety, and resilience to varying boundary conditions and production requests [1,4,12,13].

2. Summary of the Special Issue Contents

This Special Issue includes seven papers: a perspective paper to frame the ongoing advances in AI methods applications in Industrial Control Systems to realize self-optimizing manufacturing systems [1], and six papers presenting novel applications of AI methods with reference to specific control problems and different application sectors [5–10]. Further details about the seven articles are provided in the following.

The perspective paper "Advances in Artificial Intelligence Methods Applications in Industrial Control Systems: Towards Cognitive Self-Optimizing Manufacturing Systems", by Emanuele Carpanzano and Daniel Knüttel [1], provides an overview of the recent progress on different hierarchic and functional levels of industrial control solutions, discussing how AI-based methods enable further enhancements in many applications and sectors. Promising algorithms and methods are presented and discussed for every control level following a bottom-up approach, starting from the sensor level and data fusion to more complex applications such as self-optimizing machines. It is outlined how the combination of advanced monitoring, modeling, control and scheduling methods will, in the future, allow for the development of self-optimizing machines, leading to production machine improvements in terms of product quality, productivity and resource efficiency, and representing a crucial point for the next generation of human-centric manufacturing systems.

The article "*Adaptive Optimal Robust Control for Uncertain Nonlinear Systems Using Neural Network Approximation in Policy Iteration*", by Dengguo Xu, Qinglin Wang and Yuan Li [5], presents an optimal adaptive control approach to solve the robust control problems of nonlinear systems with internal and input uncertainties, based on the policy iteration

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(PI) in reinforcement learning (RL). First, the robust control is converted into solving an optimal control containing a nominal or auxiliary system with a predefined performance index. It is demonstrated that the optimal control law enables the considered system to become globally asymptotically stable for all admissible uncertainties. Second, based on the Bellman optimality principle, online PI algorithms are proposed to calculate robust controllers for the matched and mismatched uncertain systems. The approximate structure of the robust control law is obtained by approximating the optimal cost function with the neural network in PI algorithms. Finally, to illustrate the availability of the proposed algorithm and theoretical results, some numerical examples are provided.

The paper "*Digital Twin for Designing and Reconfiguring Human–Robot Collaborative Assembly Lines*", by Niki Kousi, Christos Gkournelos, Sotiris Aivaliotis, Konstantinos Lotsaris, Angelos Christos Bavelos, Panagiotis Baris, George Michalos and Sotiris Makris [6], discusses the use of DTs (Digital Twins) for designing and redesigning flexible production systems. These systems employ mobile dual arm robots that move across the factory undertaking multiple tasks, assisting humans. Exploiting this hardware ability, the DT based re-design system generates optimal configurations in terms of layout and task plans. The solution allows for online reconfiguration of the system by (a) dynamically re-assigning the tasks when unexpected events occur, and (b) making real-time adjustments of robots' behavior to ensure collision-free trajectories generation in unstructured environments. These are achieved in addition to the sensor-based real-time scene reconstruction that is provided by the Digital Twin by synthesizing multiple sensor data. The discussed DT-based system was deployed, tested and validated in a case study from the automotive sector.

The contribution "Manufacturing Execution System Integration through the Standardization of a Common Service Model for Cyber-Physical Production Systems", by Richárd Beregi, Gianfranco Pedone, Borbála Háy and József Váncza [7], proposes a generalized common service model and architecture of CPS (Cyber Physical Systems)-based manufacturing execution systems. The core model is minimalist as far as its underlying assumptions are concerned. Hence, it does not constrain the decision autonomy of collaborating cyber-physical entities and "only" provides channels for transferring and synchronizing the information that ensues from their decisions. The proposed approach identified the elementary concepts, such as functions, calls, variables, and reports, as the basis for modeling and providing I4.0-compliant, CPS-based services in a manufacturing environment. They were developed via standardized technologies enabling semantic interoperability and openness (OPC UA, MQTT). The universal CPS-based service integration mechanism was validated in an experimental pilot production and logistics system that included a variety of heterogeneous and autonomous resources, such as manufacturing cells, AGVs, robots, and human–robot collaborative cells. These CPS components were connected and controlled via the plug and collaborate mechanism of a MES system in a number of complex scenarios.

The manuscript "*Decentralized Multi-Agent Control of a Manipulator in Continuous Task Learning*", by Asad Ali Shahid, Jorge Said Vidal Sesin, Damjan Pecioski, Francesco Braghin, Dario Piga and Loris Roveda [8], formulates a decentralized and multi-agent approach in the form of an RL (Reinforcement Learning) problem, demonstrating the possibility of decentralizing a single manipulator controller by applying multiple agents in learning continuous actions. The purpose of this paper was to compare the feasibility of decentralization for a single robot to show the modularity in the joints, as well as to make a comparison between the centralized and decentralized approach. The results show that it is possible to decentralize the control action on the robot. Using multiple agents shows the stagnation of the learning process when using the same reward function that is used for a single agent. It is believed that this is due to the lack of communication between the agents and the generality of the reward when considering two agents.

The paper "*Predictive Control for Small Unmanned Ground Vehicles* via *a Multi-Dimensional Taylor Network*", by Yuzhan Wu, Chenlong Li, Changshun Yuan, Meng Li and Hao Li [9], presents an improved predictive control scheme based on the MTN (multi-dimensional Taylor network) for tracking the control of SUGVs (Small Unmanned Ground Vehicles).

The traditional objective function was improved to obtain a predictive objective function with the differential term. The optimal control quantity was given in real time through iterative optimization. A tracking control experiment was carried out on an SUGV to verify the effectiveness of the proposed scheme. The results show that the proposed scheme is effective and has good a real-time, robustness, and convergence performance, which ensure that the vehicle can quickly and accurately track the desired yaw velocity signal and that it is superior to the traditional MTN and RBF (Radial Basis Function) predictive control schemes.

The article "*Design of a NARX-ANN-Based SP Controller for Control of an Irrigation Main Canal Pool*", by Ybrain Hernandez-Lopez, Raul Rivas-Perez and Vicente Feliu-Batlle [10], proposes a modification of the well-known Smith predictor controller, in which the internal linear model was substituted by the combination of a NARX-ANN-based model and a TD-NARX-ANN-based model, in order to take into account the dynamic nonlinearities in the effective control of water distribution in an irrigation main canal pool. By the application of system identification procedures, NARX-ANN and a TD-NARX-ANN with recurrent architectures were obtained which describe with high accuracy the non-linear dynamic behavior of the water distribution in the studied canal pool. The NARX-ANN structure with an input layer with 13 memory blocks for the input and output signals, three neurons in the hidden layer and one neuron in the output layer, provided the best model performance. A third model—which was linear and represented by a time-delay first-order transfer function—was obtained using an identification procedure. The validation results of the three models illustrate that the FIT performance indexes of the NARX-ANN-based models are higher than that of the linear model.

3. Discussion and Concluding Remarks

By means of its seven scientific papers, the present Special Issue clearly illustrates the increasing added value of the introduction of AI methods to improve the performance of control solutions with reference to different control and automation problems in different industrial applications and sectors [1,4–10], ranging from single manipulators [8] or small unmanned ground vehicles [9], up to complex manufacturing plants [7] or irrigation systems [10]. Additionally, the role of AI to improve the performance of relevant engineering methodologies and digital instruments, such as Cyber Physical Systems [7], Digital Twins and Human-Robot Collaboration [6], are also effectively addressed in the contributions to the Special Issue.

Even if many research initiatives are ongoing, such as those discussed in the present Special Issue, many relevant challenges remain to be faced in the near future to exploit the high potential of AI methods for industrial control applications. In particular, it is of major importance to support the adoption of such novel solutions in real-world industrial applications, as well as by small- and medium-sized companies [2,3,11], and to integrate AI-based techniques to steer the co-evolution of human workers' tasks and manufacturing systems frameworks, in order to improve production systems' performance, as well as human workers' safety and well-being [12,13].

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