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EDITORIAL

Editorial for the special issue on Digital twin in industry

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Industry is a significant driver of the economics of nations across the globe. In the era of the digital economy, driven by the new generation of information technologies, such as artificial intelligence, industry internet, edge computing, cloud computing, and big data, nations prioritize intelligent development and industrial digitization for advanced manufacturing. The interconnection and integration of the physical and digital worlds are of the utmost importance.

As digital twin technology is characterized by the seamless integration between the cyber and physical spaces, it has become a crucial factor for driving innovation and competitiveness in different areas within the fast-changing corporate landscape of today [1–3]. Industries are increasingly adopting digital twin technologies to use data-driven insights as part of their digital transformation efforts. It allows for immediate monitoring, analysis, and optimization of industrial activities, resulting in improved efficiency, productivity, and cost-effectiveness [4–6]. Utilizing digital twins in industry enables organizations to discover new possibilities for optimizing processes, innovating products, and achieving sustainable growth in the age of smart manufacturing and Industry 4.0.

Furthermore, the integration of digital twin technology in industry facilitates proactive maintenance strategies, predictive analytics, and data-driven decision-making. This technology enables firms to improve their operations, minimize downtime, and boost operational effectiveness. Digital twins are crucial in industrial settings for monitoring equipment health, predicting failures, and optimizing maintenance to ensure operational reliability, maximize asset utilization, and reduce disruptions.

This special issue (SI) deals mainly with digital twin in industry. Based on the novel theories, techniques, and methods about DT, further application and development in industry are discussed.

All papers selected were undertaken the thorough review process through the journal review system, and there are 19 papers finally included in this issue. The selected papers cover a wide spectrum of topics that can be classified into four groups as follows: (1) digital twin model, (2) digital twin-based health management, (3) digital twin-based system, and (4) digital twin-based monitoring.

The first group includes 5 papers, which mainly focus on the design and validation of digital twin models. For example, Ferrari et al. presented an approach for the development of a discrete event simulation model of an automated storage and retrieval system with a perspective towards the implementation of a digital twin. Based on multi-domain, multi-level, parametric, and consistent mechatronics equipment DT mechanism model construction guidelines, a DT mechanism model construction process for mechatronics equipment is proposed by Wei et al.

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Luo et al. propose an updating method for knowledge in the virtual model driven by data. Knowledge in virtual models can be updated iteratively to accurately reproduce and track physical entity states. Yeh et al. propose a 3D part-scale finite element thermal model for multimaterials, in which the reduced-order method, flash heating, is adopted in the model to obtain good accuracy with acceptable simulation time. Wei et al. study an application-oriented reconfigured lightweight digital twin model design method for mechatronics equipment to solve the problem of simulation analysis complicated based on the digital twin model. Based on the application-oriented analysis of the system decomposition, decomposition scheme evaluation, and core module identification criteria, the core system modules for this application are identified, optimized, validated, and analyzed.

The second group comprises 6 papers, which employ digital twin technology to enhance fault diagnosis, quality prediction, assembly, and commissioning to guarantee the quality and efficiency of production. For the fault diagnosis, Xue et al. present a digital twin-driven fault diagnosis method for CNC machine tools, which can achieve accurate fault diagnosis with insufficient data. And a digital twin model library is built to guarantee that the sufficient model can represent any possible state of the physical system. For the thermomechanical coupling prediction, a digital twin-based dynamic method is proposed to predict thermomechanical coupling in the skiving process to solve the problems that the cutting force and temperature are thermomechanically coupled during the skiving process and that it is difficult to dynamically predict them. For the assembly tolerance analysis, Yi et al. propose a novel assembly tolerance analysis method considering form errors and partial parallel connections with assembly accuracy and reliability guarantees in mechanical assemblies. For the quality prediction, Ke et al. develop a hybrid neural network that combines with an autoencoder network, and a multilayer perceptron network for multi-quality predictions of injection-molded parts simultaneously predicted product width, weight, and residual stress distribution. For the commissioning, a novel virtual-real fusion commissioning method based on a digital twin production system and AR is proposed by Xu et al. For the reliability of the fracture toughness, Daoud et al. perform a reliable study of the IEF model, which calculates the critical stress intensity factor, KIC.

The third group comprises 4 papers, which introduce digital twin technology into shop floors and ports, analyzing the applicability of digital twin technology. Zhang et al. propose a data-driven smart management and control framework of a digital twin shop floor (DTS) to achieve comprehensive monitoring, accurate prediction, and rapid decision-making in a discrete manufacturing shop floor. The implementation process of the data-driven smart management and control method is defined as a six-step cycle named the CFMPOD including the collect (C), fuse (F), mirror (M), predict (P), optimize (O), and do (D) steps. In response to the demand for comprehensive and lean control on ports caused by the increase in port scale and business complexity, Yang et al. define the five-layer architecture of a digital twin port and propose a method of integration and expression of key elements, business processes, and scene rules in a virtual space based on the analysis of business characteristics of large-scale comprehensive ports. It serves as a feasible reference for future intelligent development of large ports and the application of digital twin technology. With the goal of realizing the interconnection and interoperability of a physical shop floor and corresponding digital twin, Zhang et al. propose a digital twin-based self-organizing manufacturing system (DT-SOMS). Based on the configuring of physical shop floor, digital shop floor, and DT-SOMS, the self-organizing manufacturing network and the job-machine optimal assignment mechanism and adaptive optimization control mechanism are designed. In response to the lack of systematic evaluation guidance to access the applicability of DT technology for specific applications of smart manufacturing equipment, Wei et al. propose a digital twin technology applicability evaluation method for CNC machine tool (CNCMT), by the analysis of the application-oriented requirements of DT-based CNCMT to obtain the optimal evaluation index and structure model.

Finally, the fourth group comprises 4 papers, which mainly focus on the shop floor site-related technology, such as monitoring, data perception, and data transmission. Ahmad et al. propose a method for integrating service-oriented IoT-based monitoring with the open architecture of CNC system monitoring, enabling an efficient and sufficient data acquisition, storing and processing real-time monitoring information, response, and feedback in milling process monitoring. And the proposed system comprises four main layers: the perception layer, communication layer, application layer, and CNC machine. As 5G plays an important role in many areas of smart manufacturing with the characteristics of high bandwidth, low latency, and massive connectivity, Cheng et al. review the research and application progress of 5G in manufacturing based on the communication requirement analysis for machine-to-machine, manufacturing Internet of Things, cyber-physical system-based manufacturing, logistics and supply chain, industrial Internet platform, and digital twin–driven manufacturing. In view of the problem of the composite service execution path failure caused by lack of non-adjacent-order correlation considerations, the relevant supporting data is collected by digital twin technology, so as to percept AO-C relevancy degree and calculate the relevancy degree of mix-order correlation in composite service execution path in the proposed adjacent-order correlation and non-adjacent-order correlation models by Xiang et al. Xuan et al. study the effects of Fe-6.5wt.%Si alloys prepared by different cooling methods on ordered structure and mechanical properties.

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