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Topic Insights

New Trends in Intelligent Manufacturing

Liang Gao [a], Weiming Shen [b], Xinyu Li [a]

[a] The State Key Laboratory of Digital Manufacturing Equipment and Technology, School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[b] National Research Council, Ottawa, ON K1A 0R6, Canada

Intelligent manufacturing technology has become a major trend in the development of the manufacturing industry around the world, and is being studied and applied by numerous industrially developed countries. For example, the United States has proposed an intelligent manufacturing layout based on the Industrial Internet and the "New Generation of Robots"; Germany has proposed the Industry 4.0 initiative to boost the competitiveness of the manufacturing industry through intelligent manufacturing; and the European Union (EU), Japan, Korea, China, and other large manufacturing countries have put forward corresponding strategies for the development of intelligent manufacturing. Clearly, intelligent manufacturing has become an important direction in the development of the manufacturing industry.

This special issue of *Engineering* contains ten papers—including two opinion papers and eight research papers—contributed by influential experts from China, the United States, the United Kingdom, Sweden, Japan, Singapore, and Australia. These papers focus on recent advances in a wide range of intelligent manufacturing fields, including artificial intelligence (AI) for intelligent manufacturing, design for intelligent manufacturing, human–cyber–physical system (HCPS) for intelligent manufacturing, the correlation and comparison of digital twins (DTs) and cyber–physical systems (CPSs), the design of context-aware smart products, intelligent machine tool (IMT), the online monitoring of laser welding status, anomaly diagnosis for machining processes, industrial big data analysis for manufacturing systems, and the upgrading pathways of intelligent manufacturing in China.

The opinion paper by Wang focuses on AI from intelligence science to intelligent manufacturing. Starting with a brief history of AI, the paper then provides representative examples of AI in manufacturing. Finally, the author points out the opportunities and challenges of intelligent manufacturing. New opportunities in intelligent manufacturing may include: ① remote real-time monitoring and control with little delay, ② defect-free machining by means of opportunistic process planning and scheduling, ③ cost-effective and secure predictive maintenance of assets, and ④ holistic planning and control of complex supply chains. Complexity and uncertainty are expected to remain major challenges in manufacturing in the years to come; however, AI can provide useful methods to relax or even resolve these challenges.

The opinion paper by Rosen argues that design for intelligent manufacturing (DFIM) should be considered as the design of intelligent products and services in the context of intelligent manufacturing, and specifically in regards to emerging new-generation intelligent manufacturing (NGIM) systems. This paper proposes the emerging area of product–service–system (PSS) design and suggests a framework for DFIM. It points out that DFIM comprises two aspects: first, design for possibilities and opportunities, which explores new design concepts, products, and services; and second, design to constraints, which relates to traditional design for manufacturing (DFM) seeking to avoid the constraints imposed by manufacturing process limitations.

The paper by Zhou et al. reviews the evolutionary footprint of intelligent manufacturing from the viewpoint of HCPS. In the HCPS, physical systems play the role of the main body, cyber systems the dominance, and humans the master. In the aspect of technology, HCPS can both reveal the technological principles and form the technological architecture for intelligent manufacturing. It could be concluded that the essence of intelligent manufacturing is to design, construct, and apply HCPS for various cases at different levels. In this paper, the authors discuss the connotation, characteristics, technical frame, and key technologies of HCPS for NGIM in depth. Finally, they propose an outlook to the major challenges of HCPS for NGIM.

The study by Tao et al. correlates and compares the similarities and differences between DTs and CPSs with regard to intelligent manufacturing and Industry 4.0 in detail. Both DTs and CPSs, which are very important for intelligent manufacturing, have gained extensive attention from researchers and practitioners in industry. This paper analyzes DTs and CPSs from multiple perspectives in order to highlight the differences and correlation between them. This work can help other researchers to understand and use DTs and CPSs better.

The work by Liu et al. presents a structured design framework to support the biologically inspired design (BID) of context-aware smart products. This framework is developed based on the theoretical foundations of the situated function–behavior–structure ontology. A structured design process is prescribed to leverage various biological inspirations in order to support different conceptual design activities, such as problem formulation, structure reformulation, behavior reformulation, and function reformulation.

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Existing design methods and emerging design tools are incorporated into the framework. Finally, this paper provides a case study to showcase how the framework can be followed to redesign a robot vacuum cleaner and make it more context-aware.

The study by Chen et al. reveals three stages of machine tool evolving from the manual operated machine tool (MOMT) to the IMT, and presents four intelligent control principles of the IMT in detail, including autonomous sensing and connection, autonomous learning and modeling, autonomous optimization and decision-making, and autonomous control and execution. This paper also points out that the essential characteristic of the IMT is to acquire and accumulate knowledge through learning, and presents some original key enabling technologies, such as the instruction-domain based analyzing approach, theoretical and big-data-based hybrid modeling technology, double-code control method, and so on. Based on the above research, the authors develop an intelligent numerical control system and some industrial prototype of the IMTs, and conduct three intelligent practices.

The paper by Zhang et al. reports on an online monitoring system for laser welding status. Online monitoring of welding status is crucial for the laser welding process, as it can help to enhance the strength of the joint and improve the welding efficiency. This paper establishes a deep belief network (DBN) to monitor welding status based on the real-time quantized features of the welding process. Furthermore, a genetic algorithm is applied to optimize the parameters of the proposed DBN model. The experiments show that the DBN model can achieve good accuracy and robustness in monitoring welding status.

The work by Liang et al. presents a data-driven anomaly diagnosis system that can help to achieve zero-defect production during computer numerical control (CNC) machining processes. In this system, power data for condition monitoring are continuously collected during dynamic machining processes to support online diagnosis analysis. Preprocessing mechanisms have also been designed to de-noise, normalize, and align the monitored data. Important features are extracted from the monitored data, and thresholds are defined to identify anomalies. Based on the historical data, a fruit fly optimization algorithm is applied to optimize the values in order to achieve more accurate detection.

The study by Wang et al. proposes a fog-computing-based industrial big data integration and sharing (IBDIS) approach called "Fog-IBDIS" to manage and provide data for big data analysis for manufacturing systems. First, a task flow graph (TFG) is designed to model the data analysis process. Next, the paper presents the function of Fog-IBDIS in enabling data integration and sharing with five modules: TFG management, compilation and running control, a data integration model, a basic algorithm library, and a management component. Finally, a case study is presented to illustrate the implementation of Fog-IBDIS, which ensures raw data security by deploying the analysis tasks executed by the data generators, and eases the network traffic load by greatly reducing the volume of transmitted data.

The work by Zhou et al. addresses the question by conducting multiple case studies: Can Chinese firms upgrade intelligent manufacturing in different pathways compared to the sequential one in developed economies? This study finds that Chinese manufacturing firms have a variety of pathways to transit across three technological paradigms of intelligent manufacturing—in parallel rather than in series. This implies that Chinese firms may strategize their own upgrading pathways toward intelligent manufacturing according to their capabilities and industrial specifics; and this result can be also extended to other catching-up economies. Finally, the authors provide a strategic "roadmap" as an explanatory guide to manufacturing firms, policy makers, and investors.

We would like to extend our appreciation to all the authors who have submitted their impressive works for this special issue. We are also grateful to all the reviewers for their service and commitment to this journal through their rigorous reviews, timely responses within a tight schedule, and insightful and constructive comments that helped shape the outcome of this issue. Special thanks go to the journal's support team for making this issue possible. In future, we believe that more and more AI-related and big-data-driven works will emerge in all aspects of manufacturing. This shift will enable manufacturing systems to become increasingly agile; to develop high quality, high efficiency, personalized customization, and environmental sustainability; and to promote humanity's comfort and quality of life.