Cloud-Based Cyber-Physical Systems in Manufacturing

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Preface

New technologies in manufacturing are tightly connected to innovation. They have thus been the key factors that support and influence a nation's economy since the eighteenth century, from stream engines to Industry 4.0. As the primary driving force behind economic growth and sustainable development, manufacturing serves as the foundation of and contribute to other industries, with products ranging from heavy-duty machinery to hi-tech home electronics. In the past centuries, they have contributed significantly to modern civilisation and created the momentum that still drives today's economy and society. Despite many achievements, we are still facing challenges due to growing complexity and uncertainty in manufacturing, such as adaptability to uncertainty, resource and energy conservation, ageing workforce, and secure information sharing. Researchers and engineers across organisations often find themselves in situations that demand advanced new technologies when dealing with new challenges in daily activities related to manufacturing, which cannot be addressed by existing approaches.

Targeting the challenges in solving daily problems, over the past a few years, researchers have focused their efforts on innovative approaches to improving the adaptability to complex situations on shop floors and energy efficiency along the life cycle of products. New technologies and innovations include cyber-physical system (CPS), cloud manufacturing (CM), Internet of Things (IoT), big data analytics, which are related to embedded systems and system of systems. These new technologies are now driving industry towards yet another revolution and are referred to the German initiative Industry 4.0. While these efforts have resulted in a large volume of publications recently and impacted both present and future practices in factories and beyond, there still exists a gap in the literature for a focused collection of knowledge dedicated to cloud-based CPS in manufacturing. To bridge this gap and present the state of the art to a much broader readership, from academic researchers to practicing engineers, is the primary motivation behind this book.

The first three chapters form Part 1 of this book on the literature surveys and trends. Chapter 1 begins with a clear definition of cloud computing (CC) versus cloud manufacturing (CM). CC and CM represent the latest advancement and applications of the cloud technologies in computing and manufacturing, respectively. The aim of Chap. 1 is to provide a comprehensive introduction to both CC and CM and to present their status and advancement. The discussions on CC and CM are extended in Chap. 2 to cover the latest advancement of CPS and IoT, especially in manufacturing systems. To comprehensively understand CPS and IoT, a brief introduction to both of them is given, and the key enabling technologies related to CPS and IoT are outlined. Key features, characteristics, and advancements are explained, and a few applications are reported to highlight the latest advancement in CPS and IoT. Chapter 3 then provides an overview of cybersecurity measures being considered to ensure the protection of data being sent to physical machines in a cybernetic system. While common to other cybernetic systems, security issues in CM are focused in this chapter for brevity.

Part 2 of this book focuses on cloud-based monitoring, planning, and control in CPS and is constituted from four chapters. Targeting distributed manufacturing, the scope of Chap. 4 is to present an Internet- and web-based service-oriented system for machine availability monitoring and process planning. Particularly, this chapter introduces a tiered system architecture and introduces IEC 61499 function blocks for prototype implementation. It enables real-time monitoring of machine availability and execution status during metal-cutting operations, both locally or remotely. The closed-loop information flow makes process planning and monitoring two feasible services for the distributed manufacturing. Based on the machine availability and the execution status, Chap. 5 introduces Cloud-DPP for collaborative and adaptive process planning in cloud environment. Cloud-DPP supports parts machining with a combination of milling and turning features and offers process planning services for multi-tasking machining centres with special functionalities to minimise the total number of set ups. In Chap. 6, the Cloud-DPP is linked to physical machines by function blocks to form a CPS. Within the CPS, function blocks run at control level with embedded machining information such as machining sequence and machining parameters to facilitate adaptive machining. To utilise the machines properly, right maintenance strategies are required. Chapter 7 reviews the historical development of prognosis theories and techniques and projects their future growth in maintenance enabled by the cloud infrastructure. Techniques for cloud computing are highlighted, as well as their influence on cloud-enabled prognosis for manufacturing.

Sustainable robotic assembly in CPS settings is covered in Chaps. 8 through 11 and organised into Part 3 of this book. Chapter 8 explains how to minimise a robot's energy consumption during assembly. Given a trajectory and based on the inverse kinematics and dynamics of the robot, a set of attainable configurations for the robot can be determined, perused by calculating the suitable forces and torques on the joints and links of the robot. The energy consumption is then calculated for each configuration and based on the assigned trajectory. The ones with the lowest energy consumption are chosen for robot motion control. This approach becomes instrumental and can be wrapped as a cloud service for energy-efficient robotic assembly. Another robotic application is for human–robot collaborative assembly. Chapter 9 addresses safety issues in human–robot collaboration. This chapter first reviews the traditional safety systems and then presents the latest accomplishments in active collision avoidance through immersive human–robot collaboration by using two depth cameras installed carefully in a robotic assembly cell. A remote robotic assembly system is then introduced in the second half of the chapter as one cloud robotic application. In Chap. 10, recent cloud robotics approaches are reviewed. Function block-based integration mechanisms are introduced to integrate various types of manufacturing facilities including robots. By combining cloud with robots in form of cloud robotics, it contributes to a ubiquitous and integrated cloud-based CPS system in robotic assembly. Chapter 11 further explores the potential of establishing context awareness between a human worker and an industrial robot for physical human–robot collaborative assembly. The context awareness between the human worker and the industrial robot is established by applying gesture recognition, human motion recognition, and augmented reality (AR)-based worker instruction technologies. Such a system works in a cyber-physical environment, and its results are demonstrated through case studies.

In Part 4 of this book, the aspect of CPS systems design and lifecycle analysis is shared by Chaps. 12–15. Chapter 12 presents the architecture design of cloud CPS in manufacturing. Manufacturing resources and capabilities are discussed in terms of cloud services. A service-oriented, interoperable CM system is introduced. Service methodologies are developed to support two types of cloud users, customer user versus enterprise user, along with standardised data models describing cloud service and relevant features. Two case studies are revealed to evaluate the system. System design is extended in Chap. 13 to cover lifecycle analysis and management of products. In this chapter, CM is extended to the recovery and recycling of waste electrical and electronic equipment (WEEE). Cloud services are used in the recovery and recycling processes for WEEE tracking and management. These services include all the stakeholders from the beginning to the end of life of the electrical and electronic equipment. A product tracking mechanism is also introduced with the help of the quick response (QR) code method. Chapter 14 focuses on big data analytics. In order to minimise machining errors in advance, a big data analytics-based fault prediction approach is presented for shop-floor job scheduling, where machining jobs, machining resources, and machining processes are represented by data attributes. Based on the available data on the shop floor, the potential fault/error patterns, referring to machining errors, machine faults, maintenance states, etc., are mined to discover unsuitable scheduling arrangements before machining as well as the prediction of upcoming errors during machining. Chapter 15 presents a summary of the current status and the latest advancement of CM, CPS, IoT, and big data in manufacturing. Cloud-based CPS shows great promise in factories of the future in the areas of future trends as identified at the end of this chapter. It also offers an outlook of research challenges and directions in the subject areas.

All together, the fifteen chapters provide an overview of some recent R&D achievements of cloud-based CPS applied to manufacturing, especially machining and assembly. We believe that this research field will continue to be active for years to come.

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