Springer Series in Wireless Technology

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Houbing Song
Danda B. Rawat *Editors*

Industrial Internet of Things

Cybermanufacturing Systems

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Editors
Sabina Jeschke
RWTH Aachen University
Aachen
Germany

Houbing Song
West Virginia University
Montgomery, WV
USA

Christian Brecher
RWTH Aachen University
Aachen
Germany

Danda B. Rawat
Howard University
Washington, DC
USA

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Foreword

Cyber-Physical Systems for Production Technology

It seems world-famed engineer and inventor Nikola Tesla already predicted the mobile phone about a hundred years ago when he said:

> When wireless is perfectly applied, the whole earth will be converted into a huge brain, which in fact it is, all things being particles of a real and rhythmic whole. A man will be able to carry one in his vest pocket. (Nikola Tesla, 1926)

He had already foreseen that if we could gather all the information in the world, we would indeed get very different insights on how processes are running. And this is exactly the vision of the Internet of Things (IOT) and cyber-physical systems (CPS): Networking everything to facilitate access and enhance performance. The term "cyber-physical system" emerged around 2006, when it was coined by Helen Gill at the National Science Foundation in the USA. She associated the term "cyber" to such systems, which are used for discrete processing and communication of information, while with "physical" the natural man-made technical systems are meant which operate continuously.

> Cyber-physical systems are physical, biological, and engineered systems whose operations are integrated, monitored, and/or controlled by a computational core. Components are networked at every scale. Computing is deeply embedded into every physical component, possibly even into materials. The computational core is an embedded system, usually demands real-time response, and is most often distributed. (Helen Gill, April 2006)

According to Gill, CPSs are therefore systems where virtual and real systems are linked closely at various levels and the components are networked at every scale. As an intellectual challenge, CPS is about the *intersection*, not the union, of the physical world and the cyberspace.

However, the roots of the term CPS are older and go deeper. It would be more accurate to view the terms "cyberspace" and "cyber-physical systems" as stemming from the same root "cybernetics," rather than viewing one as being derived from the other. The term "cybernetics" was coined by Norbert Wiener in 1948.

Wiener—an US mathematician and later Nobel Laureate—had a huge impact on the development of control systems theory. He described his vision of cybernetics as the conjunction of control and communication. His notion of control was deeply rooted in closed-loop feedback, where the control logic is driven by measurements of physical processes, and in turn drives the physical processes. Even though Wiener did not use digital computers, the control logic is effectively a computation, and therefore, cybernetics is the conjunction of physical processes, computation, and communication.

In the early nineties, US computer scientist Mark Weiser became well known for his concept of "ubiquitous computing." He refers to the perception of a comprehensive computerization and networking of the world and its many objects. Weiser paid early attention to the behavioral changes that occur when the environment is permeated by digital technologies and computing is made to appear anytime and everywhere. According to his vision, computers will disappear as a single device and will be replaced by "intelligent objects." To date, computers and the Internet are the subject of human attention. The so-called Internet of Things should imperceptibly support people in their activities with ever getting smaller computers, without distracting them or even get noticed.

This brings us to the differences of the Internet of Things and cyber-physical systems. Today, they are more or less synonym. The frontier between CPS and IOT has not been clearly identified since both concepts have been driven in parallel from two independent communities, although they have always been closely related. The US scientists at first used the term "Internet of Things" in 1999, more specifically Kevin Ashton, at that time an employee at Procter & Gamble. On June 22, 2009, he wrote in the RFID Journal:

> If we had computers that knew everything there was to know about things—using data they gathered without any help from us—we would be able to track and count everything, and greatly reduce waste, loss and cost. We would know when things needed replacing, repairing or recalling, and whether they were fresh or past their best. (Kevin Ashton, June 2009)

The IOT represents a major extension of the classic Internet: While the Internet is limited to the exchange of data and documents of various media types, the IOT addresses networking with everyday objects. The physical and digital world is merging. In other words, the intelligence is "embedded": Systems gain some kind of intelligence, such as cooperating robots, intelligent infrastructures, or autonomous and interconnected cars. They have certain skills to perceive their environment and communicate with each other, typically via Internet protocols. Thus, "things" are able to communicate.

This is the vision of these two great concepts—IOT and CPS—and the terms are in fact mostly interchangeable as long as we discuss their technological basis. However, the mind-set of the two concepts originates from two different communities: IOT is driven by computer sciences and Internet technologies, it understands itself as an extension of the Internet concept, and it focuses on openness and networks. CPS is driven by engineering aspects and concentrates on the physical systems behind, often in a closed-loop system, which now should start to communicate and cooperate with each other. This difference may be hairsplitting, but it causes huge differences in the methods applied to understand these upcoming systems. In particular, they lead to different modeling, control, and steering paradigms.

In this context, the term "Industry 4.0" was first used in 2011 at the Hannover Fair in Germany. It embraces a number of contemporary automation, data exchange, and manufacturing technologies and has been defined as follows:

> [...] a collective term for technologies and concepts of value chain organizations which draws together cyber-physical systems in first article (p. 17 (p3)), the Internet of Things and the Internet of Services. (Wikipedia on Industry 4.0, May 2016)

Industry 4.0 comprises the fourth industrial revolution driven by the Internet. It describes technological changes from today's production technology to cyber-physical production systems. Production machineries such as welding robots, conveyor belts, or transportation robots "talk" to each other and cooperate which ultimately leads to an intelligent smart factory.

Keeping in mind that research and developments on IOT and CPS are still in their infancies, the editors have compiled a book to address certain perspectives on specific technological aspects, such as communication networks for cyber-physical systems, today's applications and future potential of cyber-physical systems for agricultural and construction machinery, or approaches from the field of Machine Learning and Big Data for the Smart Factory.

The idea of this book is to use the opportunities coming along with the digitalization and modern networking technologies to record and promote the fourth industrial revolution in the area of production technology and related fields. The book documents the first steps of this revolution with a broad selection of different authors and provides food for thought for the next steps. These networking technologies are not limited to certain areas, but address broad areas of our society. Therefore, the editors asked different authors to comment on specific issues, such as today's application and future potential of CPS for agricultural and construction machinery or within wind energy or the impacts of CPS for competence management.

It is a technological book with interdisciplinary extensions, just because 4.0 will change everything but will happen with completely different approaches. It is time to deal intensively with questions of how we intend to exploit this enormous potential. Which player will be seen in future on the market? Which jobs have a future? What types and which nations lead the innovation? What does the computer intelligence mean for business models?

I am impressed by the interdisciplinary nature and the high scientific level of this book: The international composition of these 27 scientific contributions of US and European authors is quite outstanding. On the one hand, those two groups agree very closely on several of their views on CPS, but on the other hand, there are different mind-sets driven from different nationalities. Therefore, this collection is an attempt to close the "gap." The variety of articles gives excellent insights, and I hope that the reader will gain as many ideas and inspiration for their research as I did.

Prof. Dr.-Ing. Dr. h.c. Peter Göhner
Former director of the Institute of Industrial Automation and
Software Engineering at the University of Stuttgart

Author Biography

Danda B. Rawat is an Associate Professor in the Department of Electrical Engineering & Computer Science at Howard University, Washington, DC, USA. Prior to Howard University, he was with the College of Engineering & Information Technology of Georgia Southern University, Statesboro, GA as a faculty member until 2016. Dr. Rawat's research focuses on wireless communication networks, cyber security, cyber physical systems, Internet of Things, big data analytics, wireless virtualization, software-defined networks, smart grid systems, wireless sensor networks, and vehicular/wireless ad-hoc networks. His research is supported by US National Science Foundation, University Sponsored Programs and Center for Sustainability grants. Dr. Rawat is the recipient of NSF Faculty Early Career Development (CAREER) Award. Dr. Rawat has published over 120 scientific/technical articles and 8 books. He has been serving as an Editor/Guest Editor for over 10 international journals. He serves as a Web-Chair for IEEE INFOCOM 2016/2017, served as a Student Travel Grant Co-chair of IEEE INFOCOM 2015, Track Chair for Wireless Networking and Mobility of IEEE CCNC 2016, Track Chair for Communications Network and Protocols of IEEE AINA 2015, and so on. He served as a program chair, general chair, and session chair for numerous international conferences and workshops, and served as a technical program committee (TPC) member for several international conferences including IEEE INFOCOM, IEEE GLOBECOM, IEEE CCNC, IEEE GreenCom, IEEE AINA, IEEE ICC, IEEE WCNC and IEEE VTC conferences. He is the recipient of Outstanding Research Faculty Award (Award for Excellence in Scholarly Activity) 2015, Allen E. Paulson College of Engineering and Technology, GSU among others. He is the Founder and Director of the Cyber-security and Wireless Networking Innovations (CWiNs) Research Lab. He received the Ph.D. in Electrical and Computer Engineering from Old Dominion University, Norfolk, Virginia. Dr. Rawat is a Senior Member of IEEE and member of ACM and ASEE. He served as a Vice Chair of the Executive Committee of the IEEE Savannah Section and Webmaster for the section from 2013 to 2017.

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Part I
Introduction and Overview

Industrial Internet of Things and Cyber Manufacturing Systems

Sabina Jeschke, Christian Brecher, Tobias Meisen, Denis Özdemir and Tim Eschert

1 Introduction

The Internet of Things (IoT) is an information network of physical objects (sensors, machines, cars, buildings, and other items) that allows interaction and cooperation of these objects to reach common goals [2]. Applications include among others transportation, healthcare, smart homes and industrial environments [28]. For the latter, the term Industrial Internet of Things (IIoT) or just Industrial Internet is typically used, see e.g. [12]. In this book we will use IIoT synonymously to Industry 4.0 or to the original German term "Industrie 4.0". The differences between the terms or initiatives mainly concern stakeholders, geographical focus and representation [3]. Further, IIoT semantically describes a technology movement, while Industry 4.0 is associated with the expected economic impact. That is to say, IIoT leads to the Industry 4.0. But considering both as research and innovation initiatives, one will not find any technology that is claimed by only one of these. For the title, however, we chose IIoT, because it highlights the idea of networks, which is a cornerstone of many contributions in this book. Further, this book can be regarded as a manufacturing-oriented extension to our collected edition on cyber-physical systems

S. Jeschke · T. Meisen
IMA/ZLW & IfU, RWTH Aachen University, Dennewartstr. 27, 52068 Aachen, Germany
e-mail: sabina.jeschke@ima-zlw-ifu.rwth-aachen.de

T. Meisen
e-mail: tobias.meisen@ima-zlw-ifu.rwth-aachen.de

C. Brecher · D. Özdemir (✉) · T. Eschert
Laboratory for Machine Tools and Production Engineering (WZL),
RWTH Aachen University, Steinbachstrasse 19, 52074 Aachen, Germany
e-mail: D.Oezdemir@wzl.rwth-aachen.de

C. Brecher
e-mail: xcluster@wzl.rwth-aachen.de

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that contains many foundational topics of IoT [23]. Please note, that in our understanding the IIoT not only is the network of the physical objects in industry but also includes the digital representations of products, processes and factories such as 3D models or physical behavior models of machines.

In the year 2015, IoT has been declared one of the most hyped technologies [11]. Its industrial applications, i.e. IIoT, were even the focus of the World Economic Forum 2016 (*Slogan: Mastering the Fourth Industrial Revolution*). But critical voices are gaining weight. A recent edition of "Handelsblatt" (Germany's largest business newspaper) that was titled "The efficiency lie" [21] and the new book by the economist Robert Gordon argue that the expected productivity growth from digitalization is small compared to the preceding industrial revolutions are just two examples of this counter movement [14].

In the light of these critical voices it is even more important to analyze where real value can be gained from IIoT in terms of time, flexibility, reliability, cost, and quality. Therefore, we and the other editors are pleased to present many contributions with specific manufacturing applications and use cases in this book. But beyond these concrete scenarios we want to convey the vision of cognitive self-optimizing production networks enabling rapid product innovation, highly individual products and synchronized resource consumption. Therefore, the contributions of this book and the results of the large research initiatives associated with IIoT and Industry 4.0 represent a first step towards these results.

To guide the reader through the book, we will first give a short overview on the history and foundations of IIoT and define the key-terms of this book. Subsequently, the reader may find our overview on global research initiatives helpful for understanding the contributions of this book in the international context. The reader will find slightly different definitions of the key terms throughout the chapters of this book due to these different initiatives. But to give some orientation to the reader, the last part provides a brief summary of the chapters of this book considering the challenges, solutions and forecasts for IIoT.

2 Foundations of the Industrial Internet of Things and Cyber Manufacturing Systems

IIoT has grown from a variety of technologies and their interconnections. In manufacturing, the first attempts to create a network of "things" date back to the 1970s and were summarized with the term "Computer-Integrated Manufacturing" (CIM). Although the ideas of CIM are now approximately 40 years old, most challenges are still prevailing today, e.g. the integration of managerial and engineering processes and the realization of flexible and highly autonomous automation. However, in the 1990s—with the rise of Lean Production—excessive IT solutions were increasingly regarded as inefficient and many CIM projects as a failure. In retrospective, the early disappointments can be traced back to the reason that technology and people were not ready to successfully implement the ideas, e.g.