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Dietmar P.F. Möller

Guide to Computing Fundamentals in Cyber-Physical Systems

Concepts, Design Methods, and Applications

Springer

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Foreword

Changing market dynamics are reviving up the manufacturing and automotive industry. Consumers, today, are not looking only for a car, but in fact seek a bundled experience package. Manufacturers are turning to automation as a means to improve quality, productivity, safety, speed, and competitiveness while reducing costs. The evolving technology investment environment has a deep influence and impact on how value chain collaboration, internal operations, and customer experience for both products and services will emerge in the immediate future. The automotive industry has always been at the forefront in defining new paradigms for the manufacturing industry. This book outlines internal research and experience gained over multiple engagements of digitization of manufacturing industry.

Digital Manufacturing/Industry 4.0 is the transformation of manufacturing under conditions of adequately adapted automated manufacturing systems. Thus, digital technological trends are in the focus that is aimed at a novel method of manufacturing automation. The chapters in the book involve the use of digital models and methods of manufacturing planning and control and linking them to real manufacturing subsystems, manufacturing components (hardware), and tools (software).

The central feature of the book is networking the networked virtual computer world (cyber) with the manufacturing components world (physical) through cyber-physical systems. Therefore, cyber-physical systems in this sense can be introduced as a strong digital platform – well structured and well integrated – and only as complex as absolutely necessary with regard to the designated use in manufacturing. Thus, cyber-physical systems-based organized manufacturing systems will be able to largely control, depending on external requirements independently and autonomously, optimize, and configure what outruns on an outstanding automation level.

The core research areas are advanced methodologies to study systems as physical components and the Internet as the cyber part of cyber-physical systems which are essential. This book *Guide to Computing Fundamentals in Cyber-Physical Systems: Concepts, Design, Methods, and Applications* is a showcase of creative ideas of ongoing research work and fundamentals focusing on systems and software engineering of cyber-physical systems. The book shows how to analyze the

intrinsic complexity of cyber-physical systems accurately and under varying operation conditions and scenarios to predict its behavior for engineering and planning purposes to provide adequate academic answers for today's emerging technology management questions in Digital Manufacturing/Industry 4.0. The chapters are well written showing academic rigor and professionalism of the author. Therefore, the book can be stated as an important reading for new researchers entering this field of cyber-physical systems research. It offers new perspectives and documents important progress in Digital Manufacturing/Industry 4.0 analysis and development.

I strongly recommend Prof. Dietmar P.F. Moeller's scholarly writing to students, academicians, and industrialists who are keen to learn advance methodologies in manufacturing. I can say without reservation that this book, and, more specifically, the method it espouses, will change the fundamental ideas for better innovation and digital disruption of manufacturing and automotive industry. Which will be a new wave of digital disruption-led consumerization as a result of the power and impact of converging technologies like big data, high-performance computing, cloud, mobility, and social media, enabling automotive enterprises to explore new business models and differentiation opportunities, both on the production side and the customer engagement side of the business? I failed to mention how much more I enjoy reading and reviewing the book. I think that the author can be confident that there will be many grateful readers who will have gained a broader perspective of the disciplines of digital manufacturing and cyber-physical system as a result of their efforts.

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Preface

The goal of this book is to provide a comprehensive, in-depth, and state-of-the-art summary of cyber-physical systems and their applications. It describes the cyber-physical systems approach, clearly showing where the multitude of cyber-physical systems activities fit within the overall effort and providing an ideal framework for understanding the complexity of cyber-physical systems. For this reason, some choices have been made in selecting the material for this book. A top-down approach was taken that introduces the fundamentals of systems and embedded computing systems and focuses on the requirements of cyber-physical systems and the Internet of Things, the most important subject areas. Furthermore, ubiquitous computing is introduced, describing how current technologies, such as smart things and services with some kind of attachment, embedment, blend of tiny computers, sensors, tags, networks, smart devices, and others, relate to and support a vision for a greater range of tiny computer devices, used within the greater scope of cyber-physical systems. This provides a framework within which the reader can assimilate the associated requirements. Without such a reference, the practitioner is left to ponder the plethora of terms, standards, and practices that have been developed independently and that often lack cohesion, particularly in nomenclature and emphasis. Therefore, this book is intended to both cover all aspects of cyber-physical systems and to provide a framework for the consideration of the many issues associated with cyber-physical systems in Digital Manufacturing/Industry 4.0. These subjects are discussed with regard to individualized production, networked manufacturing, and concurrent open and closed product lines as part of cyber-physical systems applications and their respective methods in systems and software engineering.

First, an overview on the study of systems is given introducing four basic steps: (1) modeling, (2) setting up mathematical equations to describe systems using the standard forms of input–output and state variable descriptions, (3) analyzing systems, and (4) designing systems. In addition, the mathematical background of the expansion of systems, in regard to embedded computing systems, is introduced. Embedded computing systems are dedicated, computer-based systems for specific applications or products, and their importance as a platform for cyber-physical systems is discussed.

Second, cyber-physical systems, a new generation of engineered systems, are described in detail. They are the most important component within the Digital Manufacturing/Industry 4.0 paradigm shift, together with the Internet of Things, a global system of interconnected computer networks that use the standard Internet Protocol Suite (TCP/IP) to serve billions of users worldwide. Based on that foundation, ubiquitous computing (also referred to as pervasive computing) is introduced. How current technologies (smart things or objects), with some kind of attachment, embedment, blending of computers, sensors, tags, networks, and others (smart devices (mobile, wearable, wireless), smart environments (embedded computing systems, sensor-actor networks), and smart interaction (tight integration of and coordination between devices and environments, anything with everything), relate to and support a computing vision of greater availability and range of computer devices is described. With regard to the intrinsic complexity of the aforementioned approaches, systems and software engineering are the interdisciplinary approaches required to design complex technical systems based on certain thought patterns and basic principles of targeted design in terms of cyber-physical systems as intelligent and networked components in Digital Manufacturing Systems/Industry 4.0, a smart factory approach.

However, a textbook cannot describe all of the innovative aspects of cyber-physical systems and Digital Manufacturing/Industry 4.0 in detail. For this reason, the reader is referred to specific supplemental material, such as textbooks, reference guides, user manuals, etc., as well as Internet-based information which addresses several of the topics selected for the book.

Third, some actual case studies from different kinds of industrial and academic research and practice are presented to illustrate the actual state of the art and the ongoing research aspects in the context of Digital Manufacturing/Industry 4.0.

This book can serve as textbook or a reference book for college courses on cyber-physical systems and can be offered in computer science, electrical and computer engineering, information technology and informations systems, applied mathematics, and operations research as well as business informatics and management departments. The contents of the book are also very useful to researchers who are interested in the design of cyber-physical systems. Company engineers in the private sector can use the principles described in the book for their product designs.

The material in the book can be difficult to comprehend if the reader is new to such an approach. This is also due to the fact that cyber-physical systems and Digital Manufacturing/Industry 4.0 is a multidisciplinary domain, founded in computer science, engineering, mathematics, operations research, and more. The material may not be read and comprehended quickly or easily. Therefore, specific case studies have been included with related topics to help the reader master the material. It is assumed that the reader has some knowledge of basic calculus-based probability and statistics and some experience with systems and software engineering.

The book can be used as the primary text in a course in various ways. It contains more material than can be covered in detail in a quarter-long (30-h) or semester-long (45-h) course. Instructors may elect to choose their own topics and add their

own case studies. The book can also be used for self-study as a reference for engineers, scientists, and computer scientists for on-the-job training, for study in graduate schools, and as a reference for cyber-physical systems and Digital Manufacturing/Industry 4.0 practitioners and researchers.

For instructors who have adopted the book for use in a course, a variety of teaching support materials are available for download from www.springer.com/book/9783319251769. These include a comprehensive set of PowerPoint slides to be used for lectures and all video-recorded classes.

The book is divided into eight chapters which can be read independently or consecutively.

Chapter 1, "Introduction to Systems," covers the study of systems based on the four basic steps: (1) modeling, (2) setting up mathematical equations to describe systems using the standard forms of input–output and state variable descriptions, (3) analyzing systems, and (4) designing systems. It also introduces the concept of component analysis of linear systems based on the theory of controllability, observability, and identifiability, as well as analytical solutions of linear systems by analyzing their behavior and/or composite structure to examine the system response to an input demand. Finally, the approach determining the steady-state error of systems, an analysis method which defines the difference between input and output of a system in the limit as time goes to infinity, is described.

Chapter 2, "Introduction to Embedded Computing Systems," contains a brief overview of embedded computing systems and their hardware architectures and an approach for determining the design metrics of embedded computing systems, a method which defines the preciseness of a design with regard to the requirement specifications. Furthermore, the concept of embedded control with regard to the respective mathematical notation of the different control laws and the principal methodological approach to hardware-software codesign is introduced in detail.

Chapter 3, "Introduction to Cyber-Physical Systems," summarizes the knowledge from Chaps. 1 and 2 to introduce cyber-physical systems and ensure that readers from several engineering and scientific disciplines have the same understanding of the term cyber-physical systems. These systems use computations and communication deeply embedded in and interacting with physical processes by adding cyber capabilities to physical systems. Therefore, Chap. 3 concentrates on recommendations with regard to cyber-physical systems design with a focus on the cyber-physical systems requirements used to emphasize disciplined approaches to their design. Cyber-physical systems cover an extremely wide range of application areas, which allows systems to be designed more economically by sharing abstract knowledge and design tools. This allows the design of more dependable cyber-physical systems by applying best practices to the entire range of cyber-physical applications. The technological and economic drivers create an environment that enables and requires a range of new capabilities. The specific topics of smart cities and the Internet of Everything are described in more detail. Smart cities are based on digital strategies which introduce how to build more and efficient infrastructure and services by making use of the Internet of Everything.

Chapter 4, "Introduction to the Internet of Things," begins with a brief introduction of the global system of interconnected computer networks that use the standard Internet Protocol Suite (TCP/IP) to serve billions of users worldwide and identifies the enabling technologies for its use. Furthermore, radio frequency identification (RFID), a wireless automatic identification technology, is described in detail as well as the concept of wireless sensor network technology, which has important applications, such as remote environmental monitoring and target tracking. This technology has been enabled by the availability of sensors that are smaller, cheaper, and intelligent. The importance of power line communication technology, enabling data to be sent over existing power cables, is introduced with regard to the smart home application domain.

Chapter 5, "Ubiquitous Computing" (also referred to as pervasive computing), describes how current technologies (smart things or objects), with some kind of attachment, embedment, blending of computers, sensors, tags, networks, and others (smart devices (mobile, wearable, wireless), smart environments (embedded computing systems, sensor-actor networks), and smart interactions (tight integration of and coordination between devices and environments, anything with everything), relate to and support a computing vision for a greater availability and range of computer devices. Therefore, it covers the important topics of tagging, sensing, and controlling in ubiquitous computing and possible applications, such as autonomous systems, for which their behavior and composite structure is analyzed in regard to a fault-tolerant behavior.

Chapter 6, "Systems and Software Engineering," introduces, from a general perspective, the intrinsic complexity of the aforementioned approaches to systems and software engineering as an interdisciplinary field of engineering that primarily focuses on how to successfully design, implement, evaluate, and manage complex engineered systems over their life cycles. It discusses the design challenges in cyber-physical systems and their impact on systems engineering with reference to requirements definition and management using Cradle®. Cradle® is a requirements management and systems engineering tool that integrates the entire project life cycle into one, massively scalable, integrated, multiuser software product. Furthermore this chapter introduces the principal concept of software engineering with special focus on the V-model and the Agile software development methodology. It also introduces different requirements in software design in cyber-physical systems.

Chapter 7, "Digital Manufacturing/Industry 4.0," begins with a brief introduction to manufacturing and the enabling technologies and their opportunities with regard to the sequence of industrial revolutions. It also introduces digital manufacturing in reference to smart and Agile manufacturing and smart factories, one of the major concepts of Digital Manufacturing/Industry 4.0. Based on that knowledge, Chap. 7 introduces the principal concept of individualized production, an important application in the area of smart factories, and refers to networked manufacturing-integrated industry and the idea of smart supply chains that enable product data to be sent over the Internet for service purposes and more. Furthermore, the paradigm of open and closed manufacturing lines is discussed along with

the important topic of cyber security in Digital Manufacturing/Industry 4.0. Moreover, insight into Digital Manufacturing/Industry 4.0 projects in the industrial and academic research areas is given for six use cases.

Chapter 8, "Social Impact on Working Lives of the Future," gives a brief introduction to the social impact on work lives in the future by introducing the changes in skills that will occur due to the modern globalized, digital work environment as compared to the historical development of manufacturing. Therefore, it refers to the economic, social, and organizational challenges of the future of work with regard to the requirements of the digitized and automated industry. It also introduces the changing demands in the world of work in regard to the effects of Digital Manufacturing/Industry 4.0. The reader is introduced to the principal concept of greater product individualization and shifting factors of global influence with regard to the digital transformation.

Besides the methodological and technical content, all of the chapters in the book contain chapter-specific comprehensive questions to help students determine if they have gained the required knowledge, identify possible knowledge gaps, and conquer them. Moreover, all chapters include references and suggestions for further reading.

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