Industrial Internet of Things and Cyber Manufacturing Systems

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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

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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.

- Immature IT and communication infrastructure
- Lack of computational power
- Lack of data storage capacity
- Limited connectivity and data transfer rates
- Missing openness of software tools and formats for data exchange.

Moreover, the CIM movement reached its peak before the great breakthrough of the internet between the mid-1990s and the first years of the new millennium. Now, it is difficult to imagine a world without the internet. However, in the 1980s it was difficult to convey the idea of ubiquitous connectivity. In retrospective, it was almost impossible to realize information exchange on a broad scale within the factory at a time when the rest of the world was mostly not digitally connected.

While CIM was focusing on solutions for the shop floor, Product Data Management (PDM) has been established as a new approach to design networks within engineering departments connecting product data and people. In contrast to CIM, PDM was less a technology push, but originated from the limits of handling large amounts of product data with simple file based systems. Functions like product configuration, workflows, revisions, or authorization are now indispensable for engineering departments in large enterprises and are increasingly important for medium-sized companies. With Product Lifecycle Management (PLM) the network idea is taken further, considering consistent data management as an objective for the whole lifecycle [8]. In this context, PDM is usually regarded as the backbone of PLM, providing interfaces to different applications during the lifecycle such as production and service. Therefore, PDM and PLM are also a prerequisite for IIoT: The industrial “things” require product data as a basis for a meaningful communication, e.g. for comparing measurement data to the initially specified requirements associated with the product.

From the perspective of factory planning and operation, the Digital Factory aims to integrate data, models, processes, and software tools [17, 25]. Therefore, the Digital Factory is a comprehensive model of the real factory that can be used for communication, simulation and optimization during its life cycle. Software products in the domain of the Digital Factory typically come with different modules enabling functions such as material flow simulation, robot programming and virtual commissioning. In the context of IIoT, the Digital Factory can be regarded as the complement to PLM. While PLM aims to integrate data along the product life cycle, the Digital Factory comprises the data of production resources and processes. For the IIoT both are necessary, high-fidelity models of the product and its production, see Fig. 1.

While PLM and the Digital Factory contribute to the data backbone of the IIoT, many ideas of designing the hardware for IIoT can be traced back to the idea of mechatronics and Cyber-Physical Systems (CPS). Mechatronics is typically defined as the discipline that integrates mechanics, electronics and information technology [25]. As the term “mechatronics” indicates by its first syllable, the discipline can be regarded as an extension of mechanics and many of the stakeholders have a background in mechanical engineering. In contrast, the name Cyber-Physical

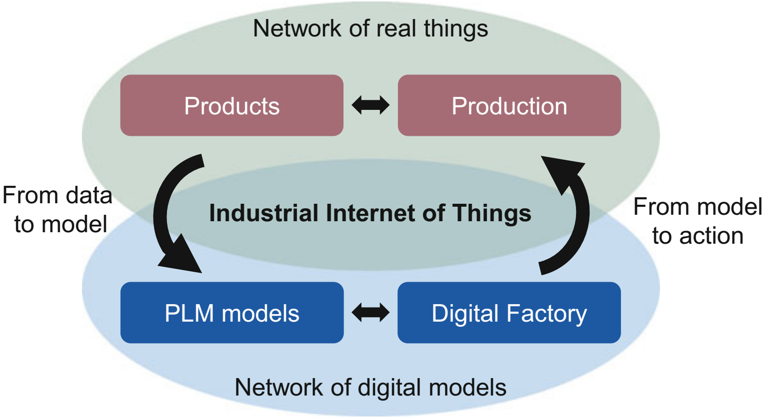

Fig. 1 IIoT as the network of real things and their digital counterparts

Systems has been established by researchers from computer science and software engineering. NASA defines CPS as an “emerging class of physical systems that exhibit complex patterns of behavior due to highly capable embedded software components” [22]. A similar definition is used in the roadmap project CyPhERS: “A CPS consists of computation, communication and control components tightly combined with physical processes of different nature, e.g., mechanical, electrical, and chemical” [6]. The latter definition could also be associated with mechatronic systems and indeed, the terms “mechatronics” and CPS are often used interchangeably, especially in the domains of automation and transport. However, the underlying “engineering philosophy” is usually different. While “mechatronics” implies that there is a physical system in the focus with a software grade-up, CPS indicates that the largest part of added-value is based on software and that the hardware-part is a special challenge for software engineering due to spatiotemporal interaction with the physical environment. Further, a CPS is characterized by the communication between subsystems that is not necessarily part of mechatronics. In this context, the CPS can be characterized as a networked system and usually the network connotation is implicitly included in the term CPS, e.g. by definitions like: CPS comprise “embedded computers and networks [that] monitor and control the physical processes […]” [18]. Taking the network idea further, CPS can be considered as “IoT-enabled” [9], where IoT implies that the subsystems are connected to the internet and therefore part of an open system with a vast number of nodes. Due to their network characteristic, CPS require a larger theoretical foundation than mechatronic systems. While the former can typically be described by the means of multi-physical modeling and control theory, the theory of the latter includes, amongst others, mechatronics, network technology, collaboration methods, cyber security, data analytics, artificial intelligence and human machine interaction. For a summary on the theory and applications of CPS we refer the collected edition of Song et al. [23] and especially to the corresponding introduction by Törngren et al. [24].

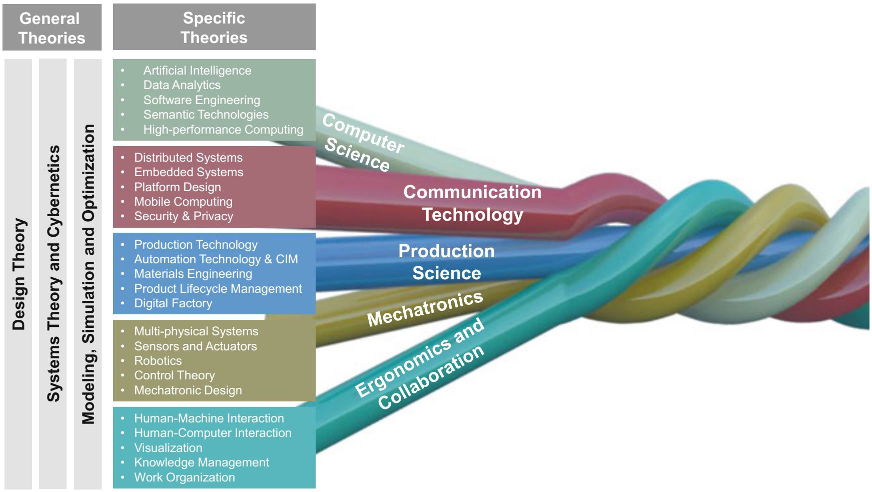

Fig. 2 Theoretical foundations of cyber manufacturing and IIoT

In the context of manufacturing, Cyber Manufacturing Systems (CMS) and IIoT denote the respective industrial counterparts of CPS and IoT. CMS or Cyber-Physical Production Systems (CPPS) are therefore advanced mechatronic production systems that gain their intelligence by their connectivity to the IIoT. Therefore, CMS cannot be considered without IIoT and vice versa. Typically, when one concept is mentioned, the other concept is implicitly included, as in the definition by Lee et al. [19]:

> “Cyber Manufacturing is a transformative concept that involves the translation of data from interconnected systems into predictive and prescriptive operations to achieve resilient performance”.

Overall, CMS and IIoT are not individual technologies with a closed theory framework, but rather an interdisciplinary blend from the domains of production, computer science, mechatronics, communication technology and ergonomics, see Fig. 2. Applications of some general theories, however, can be found across all of the disciplines. Systems theory and cybernetics can be seen as the most general approach to describe the interaction between different people and things with the aim to design cybernetic feedback loops that lead to self-optimizing and robust behavior. To understand, predict, and optimize the system behavior it is a common approach to build models that can simulate the system dynamics. Further, system design includes creative action that can generally be put into the framework of design theory, e.g. design thinking. These general theories can be considered as the “glue” for the individual domains that enables to leverage the synergy between them.

3 Potentials and Challenges

Currently, most studies agree that IIoT and CMS as promoted in initiatives such as Industry 4.0 will have a great economic impact. For example, a recent survey by PwC, a consultancy, concludes that the future global cost and efficiency gains by Industry 4.0 will exceed 400 bn. Dollars annually [13]. Countries with a large industry sector such as Germany, where industry has a 30 % share of GDP and employs 25 % of the labor force [4], are challenged by digitalization as the successful transformation to IIoT and CMS is likely to determine the future economic success of the whole economy. This transformation is especially crucial for the sector of machinery and equipment manufacturing as an enabler for other industry sectors. A recent article in the Economist put the challenge in a nutshell by asking "Does Deutschland do digital?", suggesting Germany should withdraw the reservations on platforms and data sharing and should change its corporate culture towards risk-taking and its approach to software engineering towards higher user-friendliness [7].

The transformation to Industry 4.0 is of course no end in itself, but it must lead to greater resource efficiency, shorter time-to-market, higher-value products and new services. More specifically, applications and potential benefits include:

- Intelligent automation that makes small batch sizes down to batch size one feasible because programming and commissioning efforts become negligible
- High-resolution production that improves predictability and cost transparency
- Intelligent production planning that improves the adherence to delivery dates and reduces costs and throughput times
- Predictive maintenance and automatic fault detection leading to a higher overall equipment effectiveness and a reduction of maintenance costs
- Intelligent process control aiming for zero waste, low tooling costs, minimal resource consumption and short running-in and production times
- Reconfigurability that enables quick scale-up and change management
- Human-machine interaction leading to higher labour productivity and improved ergonomics
- Feedback from production to engineering that improves the production systems of the next generation
- Implementation of new business models that leverage the seamless pipeline from customer requirements to product delivery and service

While CPS and IIoT generally have a broad field of application, as shown by the application matrix in Chap. "An Application Map for Industrial Cyber-Physical Systems", the approaches from other fields such as healthcare, transport or energy are not directly transferable. The specific points of CMS and IIoT include:

- Integration from factories to machines and their components
- Life-cycle integration of products and production resources
- Heterogeneous production infrastructure from different suppliers
- Implementation of new systems into systems of existing machinery

- Spatio-temporal relationships between objects in the system
- Broad field of manufacturing technologies
- Humans in versatile operating conditions

Generally, both CMS and IIoT can be regarded as complex systems of systems. Hence, there is not just one technological basis to build such systems, which results in a first challenge: the technological basis and suitable architectures.

A further major challenge is the specification of a generally accepted, extensible infrastructure or architectural pattern that supports, on the one hand, a variety of sensors, actuators, and other hardware and software systems, while on the other hand the complexity of the system has to remain manageable. Such a networked system contains on a small scale a sensor device, but also management or planning systems that give access to enterprise information (e.g. highly aggregated key performance indicators like the overall equipment effectiveness or a bulk of information like the stock of components, parts, and products). In order to manage the various systems and to provide a way to satisfy the information demands, researchers as well as industrials have introduced several pseudo-standardized architectural system patterns in the past. In the field of automation, exemplarily, the well-known automation pyramid or the more advanced automation-diabolo, [27] represent such architectural patterns. With the introduction of CMS and IIoT in automation, these well-structured and task-oriented patterns resolve. As shown in Fig. 3, the classical automation pyramid will be gradually replaced with networked, decentralized organized and (semi-)automated services [26]. Subsequently, new

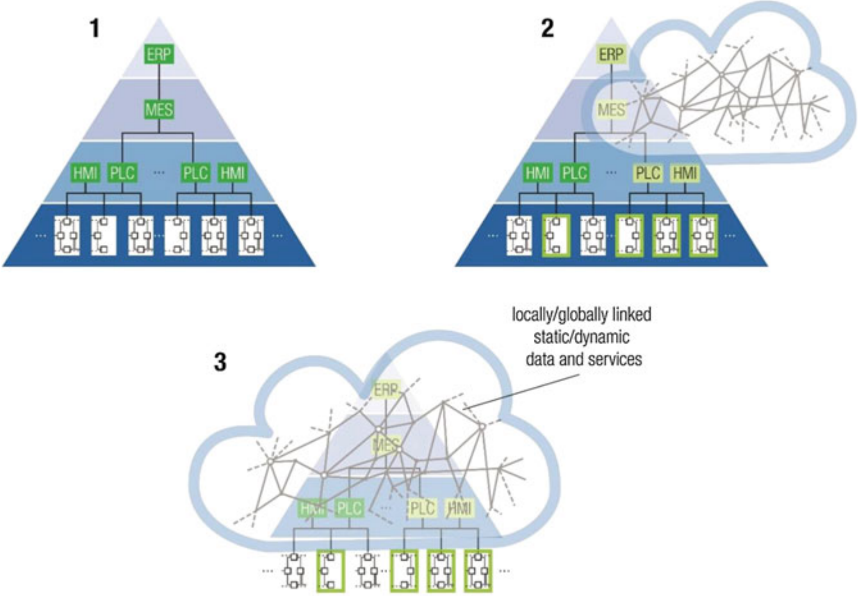

Fig. 3 Gradually replacement of the classical automation pyramid [26]

modeling and design techniques will be required for these networked structures that monitor and control physical production and manufacturing processes.

The evolving infrastructures of CMS and IIoT raise new challenges regarding communication (respectively information exchange). A transparent and adaptive communication is necessary to guarantee real-time delivery of information, robustness and other aspects of Quality-of-Service. Furthermore, such a decentralized system needs a higher level of automation regarding self-management and maintenance. Artificial intelligence and analytics need to be established to facilitate the aforementioned self-management and diagnosis capabilities. Besides, new optimization potentials can be revealed by making use of enormous amounts of gathered data.

Last, human-machine-interfaces have to be adapted reflecting the increasing complexity of these systems. It is necessary that the system ensures a timely and correct display of necessary information. Otherwise, the mass of information cannot be handled by the human worker and decisions cannot be made in time. The manner in which humans interact with the system changes—from human centered control, to an equivalent interaction, in which the cognitive capabilities of the human become central, resulting at least to an evolution of workforce.

4 Major Research Initiatives

To leverage the expected potentials of CMS and IIoT by meeting the aforementioned challenges, major research initiatives have been started across the globe. We want to give a brief summary:

(1) In Germany, major industry associations form the “Plattform Industrie 4.0” that conducts research, advocates for standardization, and coordinates technology transfer and communication between research and industry. Additionally, the topics of CPPS and IIoT are part of major research and innovation projects such as the Leading-Edge Cluster it’s OWL or the Cluster of Excellence “Integrative Production Technology for High-wage Countries” at RWTH Aachen University.

(2) The United States follow a more data-driven approach, mainly led by the “Industrial Internet Consortium (IIC)” and the “National Institute of Standards and Technology (NIST)”, the regulation agency tasked with coordinating the National Network for Manufacturing Innovation (NNMI).

(3) In Japan, most research is taking place in private companies, such as Fanuc or Fujitsu, funded by the “Ministry of Economy, Trade and Industry (METI)”.

(4) The “Ministry of Science and Technology (MoST)” is the coordinator of China’s high-tech strategy. The challenges China currently faces are different from the previously mentioned: Currently, China is a low-wage country, but wages are rising. Environmental pollution is becoming an increasing problem

but not yet fully recognized. Subsequently, technology is approached at high speed and with massive availability of capital lead.

(5) Research in South Korea is mainly driven by the Ministry of Trade, Industry and Energy (MoTIE) and the Ministry of Science, ICT and Future Planning (MSIP), together with one of Korea's largest technical universities: Korea Institute of Industrial Technology (KITECH). Korea is bringing smart manufacturing technologies to implementation, with a focus on safety and under energy constraints, as energy costs are rising.

(6) The "Ministry of Economic Affairs (MOEA)" is responsible for coordinating research in Taiwan. "Speed to market" and "Speed to volume" are the country's two main challenges. Taiwan's Foxconn is the world leader in producing ICT and semiconductors. Moreover, the biggest Taiwanese research institute in the field, The Industrial Technology Research Institute (ITRI), has a competence center for industrial research.

Thus, the way high-tech research is approached in different parts of the world is different and driven by the individual country's needs. However, a field with the global potential of the Internet of Things can only succeed if sharing knowledge and creating global standards become common goals among leaders in politics, research, and industry.

5 Approaches and Solutions

In this section, we give a short overview of the aforementioned grand challenges and the approaches and solutions that are discussed in more detail in the remaining chapters of this book. Thereby, we will extend the list of challenges regarding CMS and IIoT. However, several more technical (like safety and security aspects) as well as non-technical challenges (like suitable business models and the societal impact) exist, but are out of the scope of this book.

5.1 Modeling for CPS and CMS

Model-based design and development of production and manufacturing systems is a crucial task and has been researched for many years. Still, with the rise of CPS new challenges evolve. Nowadays, established models and methods cover e.g. different engineering and software aspects and often impose an early separation between these aspects. Thereby, modeling refers to a formalized approach facilitating the specification of the whole system or parts of it, its behavior as well as its structure. Several modeling tools and tool chains exist from both disciplines engineering as well as computer science. In the context of CPS and CMS, it is necessary to bring these solutions together.

Such integrated tool chains have to cover the different non-functional requirements as for example multidisciplinary and collaboration as well as functional requirements like the realization of hardware and software. Finally, they need to enable analysis, simulation, testing and implementation of the modelled system. Gamble et al. [10] provide an overview as well as deeper insights and discuss ongoing challenges and open research questions in this area.

In this book, modeling of CPS in general and of CMS (or CPPS) in particular is discussed from three different perspectives:

- An overview on CPS engineering for manufacturing is given in Chap. "Cyber-physical Systems Engineering for Manufacturing" from the perspective of the National Institute of Standards and Technology (NIST) in the US. The convergence of different domains poses new and great challenges to standardization tasks. While there is more or less a globally accepted way of mechanical design, there is no such standard for systems engineering. With this background, the article gives an overview on current approaches to system design with special regards to the activities of NIST.
- In Chap. "Model-Based Engineering of Supervisory Controllers for Cyber-Physical Systems" the authors discuss the modeling of supervisory controllers for CPS. Thereby, they describe a supervisory controller as the coordination component of the behavioral aspects of the CPS. Besides highlighting the steps of modeling, supervisory control synthesis, simulation-based validation and visualization, verification, real-time testing, and code generation, the chapter discusses the benefits of the Compositional Interchange Format language in this context.
- Chapter "Formal Verification of SystemC-based Cyber Components" deals with modeling of cyber components. The authors focus on the computation part of CPS—which they summarize as cyber components. Due to the increasing complexity of these components, a modeling on a high level of abstraction is necessary. They provide a new approach that transforms the SystemC model to C and embeds the Transaction Level Modeling (TLM) property in form of assertion into the C model. Furthermore, they present a new induction method for the verification of TLM properties.
- In Chap. "Evaluation Model for Assessment of Cyber-physical Production Systems" the authors examine how CPPS technology can be assessed regarding the value-adds. They give answers to the questions: "How to model the various system characteristics and abilities which are unique to Cyber-Physical Systems?" and "Which indicators and metrics could be utilized to assess the systems performances?" As a result, they provide a model of high level description of Cyber-Physical Technologies.

5.2 Architectural Design Patterns for CMS and IIoT

As pointed out, several pseudo-standardized high-level architectural system patterns exist for production systems. In addition, other domain-specific best practices have emerged over the years. But, with the introduction of CMS, these patterns are questioned. In CPPS, data, services and functions are stored and processed where they are needed and not according to the levels of the automation pyramid [26]. Hence, new design patterns arise, like service-oriented and cloud-based architectures [5, 15, 20]. For such architectures, design patterns, as pre-verified and reusable solution to a common problem in CPS, are yet to be identified and defined. Thereby, especially in the domain of production systems, migration aspects have to be covered.

In this book, such reusable and proven solutions to architectural questions are discussed in the following chapters:

- In Chap. "CPS-based Manufacturing with Semantic Object Memories and Service Orchestration for Industrie 4.0 Applications" the authors present an approach using Virtual Representation (VR). The basic idea relies on the attachment of a virtual representation and a storage space, named the digital object memory, to each physical entity. This digital shadow is furthermore used by actuators and coordination services to orchestrate the production. Furthermore, the chapter discusses additional elements of Industry 4.0 and points out its advantages like "plug'n' produce".
- The aspect of integrating robot-based CPS modules into an existing infrastructure is discussed in Chap. "Integration of a knowledge database and machine vision within a robot-based CPS". Thereby, the chapter covers applications in various industries (e.g. laundry logistics and assembly tasks). Furthermore, the authors reflect on the integration of technologies such as machine vision, RFID and physical human-robot interaction. In doing so, they also explore the possibilities for integration within heterogeneous control systems based on available standards.
- In Chap. "Interoperability in Smart Automation of Cyber Physical Systems" the authors examine interoperability on all levels of automation. They present an approach that is based on semantic technology and standardized, CPS applicable protocols like OPC UA and DDS. Further, they point out use cases, where the technology stack has been successfully used.
- Enhancing the resiliency in production facilities by using CPS, is topic of Chap. "Enhancing resiliency in production facilities through Cyber Physical Systems". Therefore, the authors first review the basic concepts of CPS in factories and their dedicated specificities. By reference to two examples, they further describe the presented concepts in actual facilities.

5.3 Communication and Networking

Humans as well as software and hardware systems produce, procure, distribute, and process data (or, if the needed capabilities are available, information) along a more or less formalized process. Initial objects of this process are data, which are collected, processed, stored, and transmitted with—in case of a technical system involvement—the help of information and communication technology. The final objects of this process are information that the user or another technical system utilize for task fulfilment or to satisfy the need for information (e.g. to make a decision).

In case of CMS, the decentralized communication and the high number of networked participants makes an adaptable and flexible information exchange between the participants necessary. In case new participants are added to the network and others are removed, the information flow still needs to be stable and reliable. In case mandatory information providers are not available, the system needs to react autonomously and accordingly. These requirements necessitate new standardized, extended protocols and network technologies for communication and networking in CPS. Existing concepts have to be analyzed and critically questioned. Semantic technologies, artificial intelligence, and context-awareness are crucial in fulfilling this challenge.

Communication and networking are discussed more detailed in:

- In Chap. "Communication and Networking for the Industrial Internet of Things ", first the characteristics and requirements of CPS are analysed and categorized. Second, the authors map the identified categories to existing communication and networking technologies to discuss the respective technologies in-depth. Thereby, they focus on their applicability to supporting CPS and shortcomings, challenges, and current research efforts.
- A similar analysis is performed in Chap. "Communications for Cyber-Physical Systems". In contradiction to the previous chapter, this one focusses on the communication within CPS in Smart Grids. The authors provide different types of communication networks for CPS that can be encountered at different system levels. They furthermore give an overview of prominent communication standards and protocols adopted in these types of CPS networks and identify open research issues that still need to be addressed.

5.4 Artificial Intelligence and Analytics

The importance of aggregating, processing, and evaluating information increases drastically in IIoT. Enabling the system to self-optimize the workflow and to identify errors and maintenance tasks on its own requires advanced analytic capabilities. Relying on human expertise alone does not work in CPS anymore. Instead, the system has to perform self-optimization as well as self-diagnosis not only based on static and perhaps configurable rules. Instead, these rules have to be adaptable by the system and according to observation of the system's states and the outcome.

Several methods from Machine Learning and Data Mining facilitate such capabilities. The analysis of huge data amounts using these methods, named Big Data Analytics, has gained a great deal of attention in the past years. The potential, not only for production scenarios, has been shown in several use cases. CMS and IIoT increase these potentials. Due to the increased data availability, these algorithms enable the system to train better models for classification, clustering, and prediction.

Methods of artificial intelligence and analytics that are suitable for CMS and IIoT as well as use cases, are discussed in:

- Chapter "Manufacturing Cyber-Physical Systems (Industrial Internet of Things)" describes the implementation of a self-learning CPS in conjunction with a knowledge database. The authors present an example that shows the planning and implementation of real physical systems using knowledge storing, complex algorithms and system structures. The described plant CPS is used for hazardous material handling, automated opening of dome covers on tank wagons for petroleum and petrochemical products.
- Chapters "Application of CPS in Machine Tools" and "Going smart—CPPS for digital production" present CPS applications for machine tools and the corresponding manufacturing processes. The former chapter includes two use cases: the intelligent chuck for a turning and the intelligent tool for milling operations. Both use cases comprise new sensor and control technologies based on analytic functions. The latter chapter focuses CPS applications for process technology on machine tools. These include, for example, the determination of process knowledge from indirect measurement signals and the corresponding visualization for the machine operator.
- Chapter "Cyber-Physical System Intelligence" focusses on systems that allow to automatically schedule, plan, reason, execute, and monitor tasks to accomplish an efficient production. Typical systems can be roughly divided in three categories: state machine based controllers, rule-based agents to more formal approaches like Golog, or planning systems with varying complexity and modeling requirements. The authors describe several approaches of all these categories and provide evaluation results from an actual implementation in a simplified Smart Factory scenario based on a group of adaptive mobile robots in simulation and real-world experiments.
- In Chap. "Big Data and Machine Learning for the Smart Factory—Solutions for Condition Monitoring, Diagnosis and Optimization" the application of Big Data platforms for factories and the modeling of formalisms to capture relevant system behavior and causalities are discussed. Further, the authors present Machine Learning algorithms to abstract system observations and give examples of the use of models for condition monitoring, predictive maintenance, and diagnosis. Finally, they demonstrate the application of models for the automatic system optimization.

- Three main milestones that have been reached in the "CPS for smart factories" activity are presented in Chap. "Overview of the CPS for Smart Factories Project: Deep Learning, Knowledge Acquisition, Anomaly Detection and Intelligent User Interfaces". First, the authors present their CPS Knowledge engineering. After that, they discuss their approach to use formal models in test scenarios to detect anomalies in physical environments. Finally, they illustrate their model based prediction with anomaly detection algorithm and the corresponding machine learning and real time verification.
- In Chap. "Applying Multi-Objective Optimization Algorithms to a Weaving Machine as Cyber-Physical Production System" the authors present a multi-objective self-optimization of weaving processes based on wireless interfaces of sensor systems and actuators. Thereby, embedded optimization algorithms enable the weaving machine to decide about optimal parameter settings autonomously. Furthermore, the weaving machine supports operators in setting up the process by providing suitable user interfaces.
- The impact of CMS and IIoT on production control and logistics is considered in Chaps. "Cyber Physical Production Control" and "A Versatile and Scalable Production Planning and Control System for Small Batch Series". The first chapter presents a general concept and first results for Cyber Physical Production Control as a means to support decision making on the basis of high-resolution real-time data. The latter chapter addresses the specific challenge of small batch sizes and presents results from the SMART FACE project from which a comprehensive CPS logistics demonstrator evolved.

5.5 Evolution of Workforce and Human-Machine-Interaction

With the introduction of CMS and IIoT the role of the today's worker will change. Competences of the future worker are focused more and more on the human cognitive capabilities. Hence, the tasks are more critical and cover for example regulating, supervising, and controlling the manufacturing process. Therefore, besides the necessity for qualification, the technical systems have to provide suitable user interfaces, enabling the user to fulfill these tasks in a proper way.

Furthermore, the interaction between human and machine advances. Collaboration between humans and machines are no more an exception. Instead, they are working as in close collaboration. These topics are covered in the following chapters:

- Chapter "CPS and the Worker: Reorientation and Requalification?" discusses the role of the future manufacturing worker. The authors demonstrate the consequences of a changing manufacturing system and give an approach how the management of a company can integrate the worker in a different way.

- In Chap. “Towards User-driven Cyber-Physical Systems—Strategies to support user intervention in provisioning of information and capabilities of cyber-physical systems” the goal is to identify challenges related to user-driven and user-defined Cyber-Physical Systems. Furthermore, the authors outline strategies to solve the identified challenges. Due to that, they describe several strategies that influence the users handling with CPS technologies.
- The technical and collaborative competency of the future employees are topic in Chap. “Competence management in the age of Cyber Physical Systems”. The authors provide a categorization of different types of competency for mastering the technological and contextual complexity of CPS. In this process, a measurement instrument for these competencies is introduced.

6 A Glance into the Future: Towards Autonomous Networked Manufacturing Systems

The potentials and challenges of CPPS and CMS have already been discussed in many publications, talks, and key notes [1, 16, 26]. Nevertheless, a reference implementation has yet to be realized and several challenges still need to be solved. But, as depicted in several scenarios in this book, first steps and solutions have been realized in the past years and there are more to come.

The introduction of CMS and IIoT in the manufacturing environment will be an evolutionary process that is also triggered by innovations from other domains. In this context the book provides examples from agricultural machinery Chap. “ Cyber-Physical Systems for agricultural and construction machinery—Current applications and future potential”, wind energy “Application of CPS within wind energy—Current implementation and future potential”, and biological tissues in Chap. “Transfer Printing for Cyber-manufacturing Systems”.

In production context, the evolutionary process will sooner or later lead to networked manufacturing systems with a high degree of autonomy. Such systems provide plug and produce as well as self-optimization and self-diagnosis capabilities. They are organized in a decentralized manner, increasing robustness and adaptability. Due to a high information transparency that has to be reached in future CMS, the production will be efficient with regards to costs and resources. A flexible and adaptable production scheduling will be possible, allowing the production of very small lot sizes.

Building innovation communities that help companies and their employees to successfully go through this digital transformation will be a key factor for economic success. In this context chapter “Advanced Manufacturing Innovation Ecosystems: The Case of Massachusetts” illustrates an economic state analysis and subsequent recommendations for creating and fostering innovation ecosystems by the case Massachusetts.

Beyond these ecosystems, we need to find answers regarding societal implications as well as legal, security, and safety aspects. Furthermore, the increased dependability on technology and providers of technological solutions require established companies to rethink long grown structures.

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References

1. Acatech (2011) National Academy of Science and Engineering. Cyber-physical systems: driving force for innovation in mobility, health, energy and production, München
2. Atzori L, Iera A, Morabito G (2010) The internet of things: a survey. Comput Netw 54 (15):2787–2805
3. Bledowski K (2015) The internet of things: industrie 4.0 vs. the industrial internet. https://www.mapi.net/forecasts-data/internet-things-industrie-40-vs-industrial-internet. Accessed 14 June 2016
4. CIA (2016) The world factbook: Germany. https://www.cia.gov/library/publications/the-world-factbook/geos/gm.html. Accessed 29 June 2016
5. Colombo AW, Bangemann T, Karnouskos S, Delsing J, Stluka P, Harrison R, Jammes F, Lastra JL (2014) Industrial cloud-based cyber-physical systems: the IMC-AESOP approach. Springer, Switzerland
6. CyPhERS (2013) Characteristics, capabilities, potential applications of cyber-physical systems: a preliminary analysis. http://www.cyphers.eu/sites/default/files/D2.1.pdf. Accessed 17 Mar 2016
7. Economist (2015) Germany's industry: does Deutschland do digital? http://www.economist.com/news/business/21678774-europes-biggest-economy-rightly-worried-digitisation-threat-its-industrial. Accessed 19 June 2016
8. Eigner M, Stelzer R (2013) Product lifecycle management: Ein Leitfaden für product development und life cycle management, 2, neu, bearb edn. VDI Springer, Dordrecht
9. Fortino G, Di Fatta G, Ochoa SF (2015) Future generation computer systems: special issue on "Cyber-physical systems (CPS), internet of things (IoT) and big data". http://www.journals.elsevier.com/future-generation-computer-systems/call-for-papers/special-issue-on-cyber-physical-systems-cps-internet-of-thin/. Accessed 27 June 2016
10. Gamble C, Larsen PG, Pierce K, Woodcock J (2015) Cyber-physical systems design: formal foundations, methods and integrated tool chains. In: 3rd FME workshop on formal methods in software engineering (FormaliSE), pp 40–46
11. Gartner (2015) Gartner's 2015 hype cycle for emerging technologies identifies the computing innovations that organizations should monitor. http://www.gartner.com/newsroom/id/3114217. Accessed 14 June 2016
12. GE (2016) Industrial internet insights: bring together brilliant machines, advanced analytics and people at work. https://www.ge.com/digital/industrial-internet. Accessed 14 June 2016
13. Geissbauer R, Vedso J, Schrauf S (2016) Industry 4.0: building the digital enterprise: 2016 global industry 4.0 survey. PwC, Munich
14. Gordon RJ (2016) The rise and fall of american growth: the US standard of living since the civil war. Princeton University Press, New Jersey
15. Hoang DD, Paik H, Kim C (2012) Service-oriented middleware architectures for cyber-physical systems. Int J Comput Sci Netw Secur 12(1):79–87

16. Kagermann H, Wahlster W, Helbig J (2013) Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0. Abschlussbericht des Arbeitskreises Industrie 4:5
17. Kühn W (2006) Digital factory: simulation enhancing the product and production engineering process. In: Winter simulation conference, pp 1899–1906
18. Lee EA (2008) Cyber physical systems: Design challenges. In: 11th IEEE international symposium on object oriented real-time distributed computing (ISORC), pp 363–369
19. Lee J, Bagheri B, Jin C (2016) Introduction to cyber manufacturing. Manuf Lett 8:12–15
20. Lin K, Panahi M (2010) A real-time service-oriented framework to support sustainable cyber-physical systems. In: 8th IEEE international conference on industrial informatics (INDIN), pp 15–21
21. Münchrath J (2016) Falsche Versprechen. Handelsblatt 70(110):44–45
22. NASA (2012) Cyber-physical systems modeling and analysis (CPSMA) initiative. http://www.nasa.gov/centers/ames/cct/office/studies/cyber-physical_systems.html. Accessed 24 June 2016
23. Song H, Rawat D, Jeschke S, Brecher C (eds) (2016) Cyber-physical systems: foundations, principles and applications. Academic Press, London
24. Törngren M, Asplund F, Bensalem S, McDermid J, Passerone R, Pfeifer H, Sangiovanni-Vincentelli A, Schätz B (2016) Characterization, analysis, and recommendations for exploiting the opportunities of cyber-physical systems. In: Song H, Rawat D, Jeschke S, Brecher C (eds) Cyber-physical systems: foundations, principles and applications. Academic Press, London, pp 3–14
25. VDI (2008) Richtlinie 2206—Digitale Fabrik Grundlagen. VDI-Verlag, Düsseldorf
26. VDI/VDE-Gesellschaft (2013) Cyber-Physical Systems: Chancen und Nutzen aus Sicht der Automation, Düsseldorf
27. Vogel-Heuser B, Kegel G, Bender K, Wucherer K (2009) Global information architecture for industrial automation. Automatisierungstechnische Praxis (atp) 51(1):108–115
28. Whitmore A, Agarwal A, Da Xu L (2015) The internet of things—a survey of topics and trends. Inf Syst Front 17(2):261–274. doi:10.1007/s10796-014-9489-2