Advances in IoT, Robotics, and Cyber Physical Systems for Industrial Transformation

CYBER-PHYSICAL SYSTEMS FOR INDUSTRIAL TRANSFORMATION

Fundamentals, Standards, and Protocols

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First edition published 2023
by CRC Press
6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742

and by CRC Press
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

CRC Press is an imprint of Taylor & Francis Group, LLC

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ISBN: 978-1-032-20162-7 (hbk)
ISBN: 978-1-032-20165-8 (pbk)
ISBN: 978-1-003-26252-7 (ebk)

DOI: 10.1201/9781003262527

Typeset in Times
by Apex CoVantage, LLC

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Preface

The advances of Cyber-Physical Systems aim to enable capability, adaptability, scalability, resiliency, safety, security, and usability that will far exceed the simple embedded systems of today. The term "Cyber-Physical Systems" (CPS) refers to a new generation of systems that combine computational and physical capabilities to interact with humans in a variety of new ways. It appears as a result of an increase in technological systems in which interactions between interconnected computer systems and the physical environment were prioritized. Cyber-physical systems (CPSs) and the Internet of Things (IoT) advancements are paving the way for a future of hyper-connected objects, computers, and humans.

Industrial transformation is happening at a never-before-seen pace. It will pave a way for an era where information technology will communicate with physical assets. As we are increasingly connected through the CPSs, more often data is transmitted in real-time while analytics occur in response to actual events.

Chapters in this book address a variety of subjects, starting with an introduction to referential architectures of Cyber-Physical Systems (CPS) for Industry 4.0 in Chapter 1. 6G network for connecting CPS and Industrial IoT (IIoT) is presented in Chapter 2. Blockchain and its relationships with CPS are illustrated in Chapters 3 and 14. Chapters 4 and 10 highlight the role of cyber-physical robotics and power systems in CPS. Cybersecurity and its related topics to Industrial CPS are introduced in Chapters 5, 6, 7, 8, and 9. In Chapter 11, the role of intelligent agents in CPS is illustrated. The applications of the Industrial CPS to healthcare are described in Chapters 12, 13, and 15.

We appreciate and recognize everyone who contributed to all phases of publication. That includes the authors, reviewers, and publishing team. Their participation and support were crucial to the success of the edited book *Cyber-Physical Systems for Industrial Transformation: Fundamentals, Standards, and Protocols*. We hope that the readers will enjoy both the chapters and their contents, in addition to the work that has gone into making it a reality.

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DOI: 10.1201/9781003262527-4

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4.1 INTRODUCTION

Regardless of the functionality mode of a robotic system, autonomous, semiautonomous (teleoperated) or automatic (repetitive algorithmic task), a robotic system is compounded by a mechanical structure, actuator/sensor devices and embedded computation that carry out the physical processes. In addition, smart robotics is comprised of computers, organization of intelligence, and when it develops mobility, it essentially requires networked robust control of the physical process subjected to cyclic feedback. Modern morphological modalities of mobile robots imply highly complex functionalities and exponentially increased multivariate calculations. For instance, self-balanced rolling bipeds performing carry-and-fetch tasks, quadruped walkers manipulating robot arms onboard, aerial robots that adapt their own fly to the environment's aerodynamics to stabilize themselves, amphibian robots with locomotive capacity both in water and on land, etc. Parallel computing resources are worth considering to conveniently suit computational intelligence functions, which are required in robotic systems. Therefore, scheduling software managing computer resources becomes relevant to be considered in the development of robotic architectures and Cyber-Physical Systems. Cyber-physical robotics depends on deterministic models that concern physical laws describing physical behaviors. Furthermore, by combining those physical laws with sensing and actuation models its complexity increases, frequently making it intractable to solve them analytically (Rigatos et al., 2020). Cyber-Physical System robotics entirely may depend on real-time computations, numerical methods for online observability and feedback control at runtime (Heikkilä et al., 2019). Observation models given by sensing models and measurement devices allow one to infer physical magnitudes. Most of the cases, measurement models about specific environmental configurations (e.g. dynamic trajectory tracking and control among moving objects), are models obtained at runtime paying a high computational cost, because it is intractable to have available an analytical deterministic model about the task in advance. Moreover, the nonlinear dynamics describing the actuating systems are, in most cases, represented by systems of non nonlinear equations, which lead us to depend on implementing recursive numerical solution methods that will exponentially increase the complexity of solutions at runtime.

Cyber-physical robotics are real-time systems purposed to develop massive computing (Lee, 2006), hence parallel capabilities inherently outperform their computability. An intelligent robot's major purpose is to deal with unpredictable dynamical environments and accomplish its task. From a computing engineering perspective, processing the challenging surrounding complexity might be consistently alleviated, as cyber-physical robotics systems are sophisticated when supported by real-time (RT) parallel embedded systems technology. RT parallel embedded systems must be capable to concurrently administrate sensing devices, massive data processing (artificial hard-thinking), planning algorithms, inter-communication tasks and control of multiple actuators, as well as synchronizing multiple inputs with respect to multiple outputs (Kortenkamp & Simmons, 2008). Therefore, RT parallel computation in cyber-physical robotic architectures is critical, particularly for long-term real world missions, where computing resources need to be highly exploited (Seok et al., 2014). The robot's fields of application are numerous: construction, inspection, manufacturing, industrial automation and assembly, carry-and-fetch (Villanueva-Chacón & Martínez-García, 2015), transportation, spatial and underwater exploration, weather monitoring, surveillance and security, search and rescue, entertainment and so forth. Robotic platforms have locomotive mechanisms comprised of actuators, end-effectors, multiple heterogeneous sensors and complex algorithms that process massive data. A physical robot asynchronously controls sensors, processes data, plans new tasks, and controls the actuator devices. Hence, the computational organization design is essential to carry out efficient tasks (M. Amoretti, 2010). Computational organization refers to the robot's intelligence scheme in both hardware and software, how they are embedded into the robot's electronic brain and how the computational resources will be managed. A robot simultaneously deploys vision sensors, light detection and ranging devices, sonars, inertial measurement units, global positioning satellite receivers, depth from images devices, and so forth. Likewise, a robot computes control algorithms and complex recursive mathematical models to control actuators in parallel. For a robot to plan intelligent algorithms it requires hard-thinking tasks that result in enormous resource consumption. In addition, a communication framework is required, depending on either the centralized or distributed (Martínez-García, y otros 2018) nature of the robotic architecture.

Nowadays, there is no RTOS for robotic architectures considered standard in terms of RT and parallel computation by the robotics community. RT robotic algorithms have to be user customized according to available computational resources and no embedded OS fully accomplishes this with the general requirements of any robotic application, such as path-tracking, autonomous navigation (Diankov & Kuffner, 2008), SLAM, behavioral robotics (Nicolescu & Mataric, 2002; Policastro et al., 2007), human-robot interaction (Carlson & Millán, 2013), networked robots (Hu et al., 2012), field/service robotics etc. Each type of application requires the use of different types of resources of the architecture system (Quigley et al., 2009; e.g. odometer, accelerometer, inclinometer, gyroscope, magnetic compass, GPS, RGB camera, LiDAR, stereo, sonar, wheels, limbs, wings, propels, fins, customized mechanisms and end-effectors).

In general, all RT OS used in robotics present a variety of advantages and disadvantages according to their applications and technological limitations. There exist a variety of parallel programming models and tools with suitability for high-performance computing (Diaz et al., 2012).

Different works on architectures have been reported with focus on hardware design and