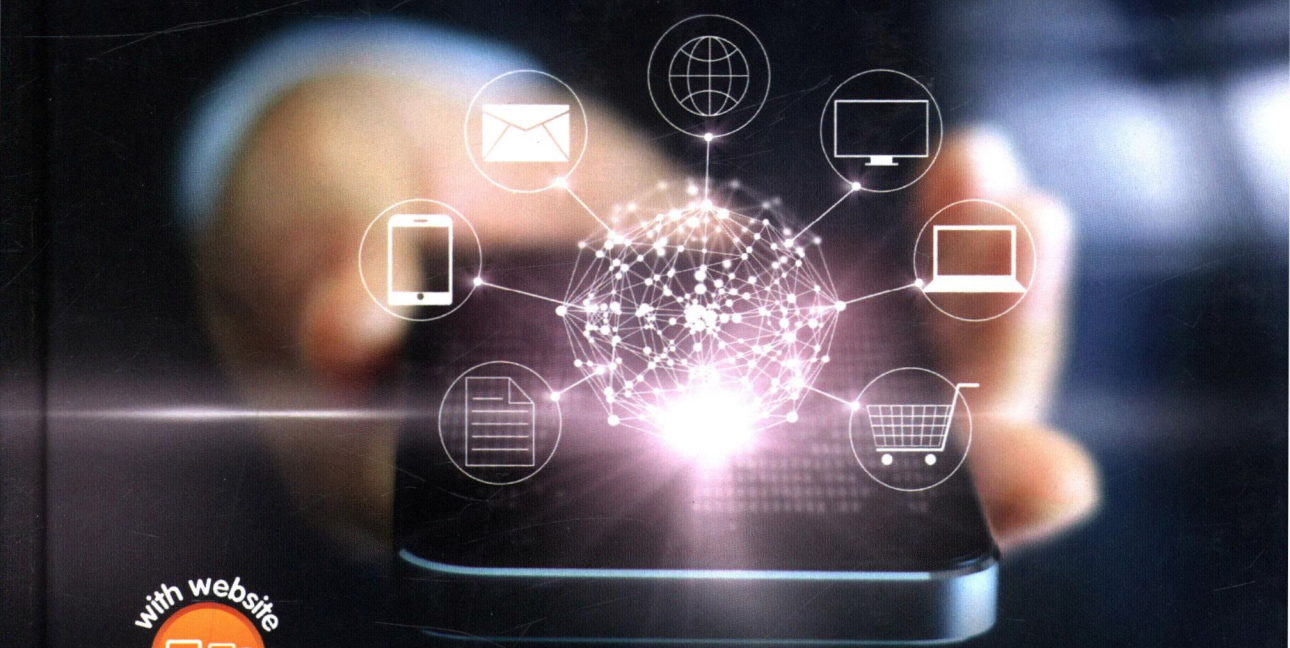
DAVID NUNES • JORGE SÁ SILVA • FERNANDO BOAVIDA

A Practical Introduction to HUMAN-IN-THE-LOOP CYBER-PHYSICAL SYSTEMS



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The first book focusing on one of the hottest new topics in Internet-of-Things systems research and development

Studies estimate that by 2020 we will have a vast Internet-of-Things (IoT) network comprising 26 billion connected devices, including everything from light bulbs to refrigerators, coffee makers to cars. From the beginning, the concept of cyber-physical systems (CPS), or the sensing and control of physical phenomena through networks of devices that work together to achieve common goals, has been implicit in the IoT enterprise. This book focuses on the increasingly hot topic of *Human-in-the-Loop Cyber-Physical Systems* (HiTLCPS)—CPS that incorporate human responses in the IoT equation.

Why have we not yet integrated the human component into CPS? What are the major challenges to achieving HiTLCPS? How can we take advantage of ubiquitous sensing platforms, such as smartphones and personal devices to achieve that goal? While mature HiTLCPS designs have yet to be achieved, or a general consensus reached on underlying HiTLCPS requirements, principles, and theory, researchers and developers worldwide are on the cusp of realizing them. With contributions from researchers at the cutting edge of HiTLCPS R&D, this book addresses many of these questions from the theoretical and practical points of view.

- An essential primer on a rapidly emerging Internet-of-Things concept, focusing on human-centric applications
- Discusses new topics which, until now, have only been available in research papers scattered throughout international literature
- Addresses fundamental concepts in depth while providing practical insights into the development of complete HiTLCPS
- Includes a companion website containing full source-code for all of the applications described

This book is an indispensable resource for researchers and app developers eager to explore HiTL concepts and include them in their designs. It is also an excellent primer for advanced undergraduates and graduate students studying IoT, CPS, and HiTLCPS.

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Cover Design: Wiley
Cover Image: © ipopba/Gettyimages

www.wiley.com/go/nunesloop

WILEY IEEE PRESS

ISBN 978-1-119-37777-1

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This edition first published 2018

Registered Office(s)
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

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Library of Congress Cataloging-in-Publication Data

Names: Nunes, David, 1987- author. | Silva, Jorge Sá, author. | Boavida, Fernando, 1959- author.
Title: A practical introduction to human-in-the-loop cyber-physical systems / David Nunes, Jorge Sá Silva, Fernando Boavida.
Description: First edition. | Hoboken, NJ : John Wiley & Sons, 2018. | Includes bibliographical references and index. |
Identifiers: LCCN 2017025006 (print) | LCCN 2017042126 (ebook) | ISBN 9781119377801 (pdf) | ISBN 9781119377788 (epub) | ISBN 9781119377771 (cloth)
Subjects: LCSH: Cooperating objects (Computer systems) | Human-computer interaction.
Classification: LCC TJ213 (ebook) | LCC TJ213 .N86 2017 (print) | DDC 621.39–dc23
LC record available at https://lccn.loc.gov/2017025006

Cover Design: Wiley
Cover Image: © ipopba/Gettyimages

Set in 10/12pt Warnock by SPi Global, Chennai, India
Printed and bound in Malaysia by Vivar Printing Sdn Bhd

10 9 8 7 6 5 4 3 2 1

A Practical Introduction to Human-in-the-Loop Cyber-Physical Systems

To my parents, Jorge and Eulália, and to my brother, Telmo.

David Nunes

To Fátima, Catarina, Pedro, Jojó, and my parents

Jorge Sá Silva

To Maria João and our three daughters – Susana, Inês, and Catarina

Fernando Boavida

Foreword

Our world keeps being an increasingly technological one. As first put forward by the renowned computer scientist Mark Weiser, we continue to see that, as devices get smaller in size, more mobile, powerful, and efficient, they begin to "disappear". Technology is now so intrinsic to our everyday lives that it has become an inherent part of our existence. This is the premise behind concepts such as the Internet of things and cyber-physical systems, in which distributed technology is used to monitor and control the environment. However, our current technological advancement still falls short of Weiser's ideas. Each time we have to hurdle through unintuitive configuration menus, errors, and software incompatibilities we become stressed by our computers and appliances. Weiser argued that the ultimate form of computers was an extension of our subconscious. To him, the ideal computer would be capable of truly understanding people's unconscious actions and desires. Instead of humans adapting to technology and learning how to use it, it would be technology that would adapt to the disposition and uniqueness of each human being.

In fact, systems that consider the human context are becoming increasingly more important, and there are strong indications that most future technologies will most likely be much more human-aware. This book focuses on the realm of human-in-the-loop cyber-physical systems (HiTLCPSs), that is cyber-physical systems that take human response into consideration. HiTLCPSs infer the user's, intents, psychological states, emotions, and actions through sensors, using this information to determine the system's actions. This involves using a large variety of sensors and mobile devices to monitor and evaluate human nature. Therefore, this technology has strong ties with wireless sensor networks, robotics, machine learning, and the Internet of things.

This book is useful to BSc and MSc students, as well as to PhD students, researchers, and professors addressing the areas of ubiquitous computing, Internet of things, cyber-physical systems, and human–computer interaction. It can also be useful to professional developers that intend to introduce HiTL concepts into their mobile apps and/or Internet of things/cyber-physical system applications.

Throughout its pages, the book will guide the reader through a journey into this novel and exciting area of research and technological development. As such, it is intended to be used as a primer on HiTLCPSs, providing some insights into the research being done on this topic, current challenges, and requirements. One of the book's objectives is to introduce the reader to the practical usage of HiTL paradigms within software development. Therefore, we included a comprehensive hands-on tutorial

where the major theoretical concepts behind HiTLCPSs are applied to a sample mobile application and explained from a practical perspective. This tutorial requires some knowledge of Android and the Java programming language, as well as some notions about databases and RESTful web services. It is accompanied by a base source code repository and several code snippets which the reader can extensively modify.[1] It is not our intention to provide in-depth knowledge about the programming languages, and/or the machine learning techniques, necessary to create complex HiTL systems. Instead, the tutorial aims at illustrating and consolidating some of the book's theoretical ideas.

Finally, we would like to thank you, the reader, for your interest. We would also like to ask you to contact us and tell us about your experience with our book. Your feedback is a very valuable resource towards improving the book. Send your email to dsnunes@dei.uc.pt, sasilva@dei.uc.pt or boavida@uc.pt.

1 The source code repositories are located at: https://git.dei.uc.pt/dsnunes/happywalk.git https://git.dei.uc.pt/dsnunes/happywalkserver.git

Preface

The Internet has changed our whole life and it will have further impact on how we live and how we work. Most of the **cyber-physical systems** (CPSs) make use of the Internet and even define parts of it. Let me cite Wikipedia in this preface, even though it is not very scientific so to do. Understanding the CPS as *"a mechanism controlled or monitored by computer-based algorithms, tightly integrated with the internet and its users"* means that users, humans, are essential for any CPS. The National Institute of Standards and Technology of the US Department of Commerce (NIST) goes even further, stating that *"these systems will provide the foundation of our critical infrastructure, form the basis of emerging and future smart services, and improve our quality of life in many areas"*. Looking at the examples mentioned in Wikipedia, *"smart grid, autonomous automobile systems, medical monitoring, process control systems, robotics systems, and automatic pilot avionics"*, human are always involved.

Humans are not only involved; humans are the essential part of CPSs; CPSs have to serve us! With the basic idea, to incorporate humans as being in the system, we encounter **human-in-the-loop** (HiTL). It comprises a model, an adequate representation of the human behavior in order to treat it as an integral part of the whole system. Just as one example, let me cite Carsten Binning *et.al.* at his preface of the Proceedings of the first Workshop on Human-In-the-Loop Data Analytics HILDA of June 26th, 2016, in San Francisco, California: *"A major bottleneck in data analytics today is to efficiently leverage the human capabilities to formulate questions and understand answers of data analytics systems ... Recent technology trends (such as touchscreens, motion detection, and voice recognition) are widening the possibilities for users to interact with data, and data-driven industries are shifting to personalized processing to better target their services to users' needs"*.

Hence it seems somewhat natural to look at both topics together in a kind of textbook and survey. In my six years as editor-in-chief of the journal *ACM Transactions on Multimedia Computing, Communications, and Applications (ACM TOMM)*, I have, unfortunately, not come across a comprehensive high-quality survey paper of CPS HiTL; it has been even more serious: nobody even tried to cover with a survey this essential area on multimedia computing, communications, and its applications. No one did so far!

At the present time, writing this preface, I was only able to read parts of this book; I am looking forward to reading it all together–the whole book.

The authors of this book, David Nunes, Jorge Sá Silva, and Fernando Boavida from the University of Coimbra provide an in-depth view to HiTLCPS evolution, theory, technologies, and applications. Moreover, they illustrate how to apply HiTLCPS

concepts to a sample smartphone application, through a hands-on approach that guides the reader from the development environment to the final product, including data acquisition, state inference, and actuation. With (1) their profound technical knowledge of many areas in computing and communications, as well as with (2) their expertise and experience as authors of other textbooks, the authors are certainly key for this book being a long-term successful scientific book in this area. Congratulations!

Dr. Ralf Steinmetz

Fellow of the IEEE and Fellow of the ACM
Director, Multimedia Communications Laboratory, Technische Universität Darmstadt
Chairman of the Board, Hessian Telemedia Technology CompetenceCenter, Germany

Darmstadt, March 2017

Acknowledgments

A book such as this would not have been possible without the help and support of many people and institutions.

First of all, we would like to thank our base institutions—the Department of Informatics Engineering, and the Center for Informatics and Systems, both from the University of Coimbra—in the scope of which we carry out our teaching and research activities, for the provided facilities and research environment. With their effort and contributions, enthusiasm, discussions, and suggestions during several years of joint research activities and human-in-the-loop social interaction, our students and our colleagues were instrumental in making this book a reality.

We also thank IMDEA Networks Institute, in Madrid, for the support provided during Fernando Boavida's sabbatical in 2015/2016, and especially to its leading computer scientist, Arturo Azcorra, for his support; to Antonio Fernández Anta, Miguel Péon, Jeanet Birkkjaer; and Rosa Gómez for their encouragement; and to all its researchers and staff in general.

Some of the research that formed the basis for this book was carried out in the scope of financed research projects and initiatives and, thus, it is also right to thank the entities that made the referred research possible, namely the Portuguese Foundation for Science and Technology (FCT), FCT's POPH/FSE program, and the SOCIALITE Project (PTDC/EEI-SCR/2072/2014), supported by COMPETE 2020, Portugal 2020, Operational Program for Competitiveness and Internationalization (POCI), and the European Union's ERDF (European Regional Development Fund).

We would also like to thank David Hutchison, from Lancaster University, for believing in us and putting us in contact with the excellent editorial team at John Wiley & Sons.

Finally, we would like to thank our families, for their unconditional love and support.

List of Abbreviations

AI	Artificial Intelligence
ANN	Artificial Neural Network
API	Application Programming Interface
AS	Android Studio
AV	Autonomous Vehicle
BCC	Body-Coupled Communication
BCI	Behavior Change Interventions
CHIL	Computers in the Human Interaction Loop
CoAP	Constrained Application Protocol
cOre	Constrained RESTful environments
CPS(s)	Cyber-Physical System(s)
CPU	Central Processing Unit
DAO	Data Access Object
ECG	Electrocardiography
EEG	Electroencephalography
ESM	Experience Sampling Method
FCT	Fast Cosine Transform
FFT	Fast Fourier Transformation
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HiTL	Human-in-the-Loop
HiTLCPS(s)	Human-in-the-Loop Cyber-Physical System(s)
HTML	HyperText Markup Language
HTTP	Hypertext Transfer Protocol
HVAC	Heating, Ventilation, and Cooling
ID	Identification
IFR	International Federation of Robotics
IoA	Internet of All
IoT	Internet of Things
IP	Internet Protocol
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
ISM band	Industrial, Scientific, and Medical radio bands

Java EE	Java Enterprise Edition
Java SE	Java Standard Edition
JDK	Java Development Kit
JSON	JavaScript Object Notation
LTE	Long-Term Evolution
M2M	Machine-to-Machine
MPTCP	MultiPath Transmission Control Protocol
NAT	Network Address Translation
NSF	National Science Foundation
OSI	Open Systems Interconnection
OS	Operating System
P2P	Peer-to-Peer
POI(s)	Point(s) of Interest
RAM	Random-Access Memory
REST	Representational state transfer
RF	Radio Frequency
RFID	Radio-Frequency Identification
RSSI	Received Signal Strength Indication
SCTP	Stream Control Transmission Protocol
SDK	Software Development Kit
sMAP	Simple Monitoring and Action Profile
SMS	Short Message Service
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
UUID	Universally Unique Identifier
VoIP	Voice Over Internet Protocol
WSDL	Web Service Description Language
WSN(s)	Wireless Sensor Network(s)
XML	Extensible Markup Language