Contents

SPECIAL SECTION

SIGNAL PROCESSING AND THE INTERNET OF THINGS

- 13 FROM THE GUEST EDITORS Chenren Xu, Yan (Lindsay) Sun, Konstantinos (Kostas) N. Plataniotis, and Nic Lane
- 16 PRACTICAL BACKSCATTER COMMUNICATION SYSTEMS FOR BATTERY-FREE INTERNET OF THINGS

Chenren Xu, Lei Yang, and Pengyu Zhang

28 THE ART OF SIGNAL PROCESSING IN BACKSCATTER RADIO FOR \nu (OR LESS) INTERNET OF THINGS

Aggelos Bletsas, Panos N. Alevizos, and Georgios Vougioukas

41 IoT SECURITY TECHNIQUES BASED ON MACHINE LEARNING Liang Xiao, Xiaoyue Wan, Xiaozhen

Lu, Yanyong Zhang, and Di Wu APPROACHES TO SECURE

50 APPROACHES TO SECURE INFERENCE IN THE INTERNET OF THINGS

Jiangfan Zhang, Rick S. Blum, and H. Vincent Poor





ON THE COVER

This special issue of *IEEE Signal Processing Magazine* provides a comprehensive view of the main advances in the Internet of Things through a number of tutorial-style articles as well as from contributions that emphasize the key topics of development in this area, both in terms of theory and applications.

COVER IMAGE: ©ISTOCKPHOTO.COW/ILYAST, ROBOT, VEHICLE, UAV ICONS COURTESY OF NURIA GONZALEZ PRELCIC

64 THE INTERNET OF THINGS Yuan Chen, Soummya Kar, and José M.F. Moura

76 SECURITY AND PRIVACY FOR THE INDUSTRIAL INTERNET OF THINGS Lu Zhou, Kuo-Hui Yeh.

Lu Zhou, Kuo-Hui Yeh, Gerhard Hancke, Zhe Liu, and Chunhua Su

88 SPARSE SIGNAL PROCESSING FOR GRANT-FREE MASSIVE CONNECTIVITY

Liang Liu, Erik G. Larsson, Wei Yu, Petar Popovski, Čedomir Stefanović, and Elisabeth de Carvalho

100 INTERNET OF THINGS FOR GREEN BUILDING MANAGEMENT

Wayes Tushar, Nipun Wijerathne, Wen-Tai Li, Chau Yuen, H. Vincent Poor, Tapan Kumar Saha, and Kristin L. Wood

111 A SURVEY ON SMART HOMES FOR AGING IN PLACE

Viswam Nathan, Sudip Paul, Temiloluwa Prioleau, Li Niu, Bobak J. Mortazavi, Stephen A. Cambone, Ashok Veeraraghavan, Ashutosh Sabharwal, and Roozbeh Jafari

120 FROM SURVEILLANCE TO DIGITAL TWIN

Yuan He, Junchen Guo, and Xiaolong Zheng

130 CROWD-BASED LEARNING OF SPATIAL FIELDS FOR THE INTERNET OF THINGS Eva Arias-de-Reyna, Pau Closas, Davide Dardari, and Petar M. Djurić

140 MICROLOCATION FOR SMART BUILDINGS IN THE ERA OF THE INTERNET OF THINGS Petros Spachos,

Ioannis Papapanagiotou, and Konstantinos N. Plataniotis

153 EFFICIENT MULTISENSOR LOCALIZATION FOR THE INTERNET OF THINGS

Moe Z. Win, Florian Meyer, Zhenyu Liu, Wenhan Dai, Stefania Bartoletti, and Andrea Conti



IEEE SIGNAL PROCESSING MAGAZINE (ISSN 1053-5888) (ISPREG) is published bimonthly by the Institute of Electrical and Electronics Engineers, Inc., 3 Park Avenue, 17th Floor, New York, NY 10016-5997 USA (+1 212 419 7900). Responsibility for the contents rests upon the authors and not the IEEE, the Society, or its members. Annual member subscriptions included in Society fee. Nonmember subscriptions available upon request. Individual opies: IEEE Members US\$20.00 (first copy only), nonmembers US\$241.00 per copy. Copyright and Reprint Permission: Abstracting is permitted with credit to the source. Libraries are permitted to photocopy beyond the limits of U.S. Copyright Law for private use of patrons: 1) those post-1977 articles that carry a code at the bottom of the first page, provided the per-copy isolated articles for noncommercial classroom use without fee. For all other copying, reprint, or republication permission, write to IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854 USA. Copyright © 2018 by the Institute of Electronics Engineers, Inc. All rights reserved. Periodicals postage paid at New York, NY, and at additional mailing offices. Postmaster: Send address changes to IEEE Signal Processing Magazine, IEEE, 445 Hoes Lane, Piscataway, NJ 08854 USA. Canadian GST #125634188 Printed in the USA.

Digital Object Identifier 10.1109/MSP.2018.2849040

COLUMNS

Society News 7

Election of Regional Directors-at-Large and Members-at-Large New Society Officer Elected and Editors-in-Chief Named for 2019

Special Reports 9

Signal Processing Opens the Internet of Things to a New World of Possibilities John Edwards

168 SP Competitions

Forensic Camera Model Identification Matthew Stamm, Paolo Bestagini, Lucio Marcenaro, and Patrizio Campisi

175 Lecture Notes

What Is a Signal? Pragnan Chakravorty Low-Rank Matrix Completion Yuejie Chi

188 In the Spotlight

Perspectives in Signal Processing for Communications and Networking Wei Yu and Joakim Jaldén

Highlights from the Sensor Array and Multichannel Technical Committee Martin Haardt, Christoph Mecklenbräuker, and Peter Willett



The IEEE International Symposium on Biomedical Imaging will be held 8-11 April 2019 in beautiful Venice, Italy

DEPARTMENTS

- From the Editor 3 GlobalSIP and Beyond Robert W. Heath, Jr.
- President's Message 4 Science Is Blind Ali H. Sayed
- **Dates Ahead** 182
- 186 Humor Convoluted Robert W. Heath, Jr. and Nuria González-Prelcic

186 For Your Consideration



IEEE prohibits discrimination, harassment, and bullying. For more information, visit http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html.

EDITOR-IN-CHIEF

Robert W. Heath, Jr. - The University of Texas at Austin, U.S.A.

AREA EDITORS

Feature Articles Matthew McKay—Hong Kong University of Science and Technology, Hong Kong SAR of China

Special Issues Namrata Vaswani–Iowa State University, U.S.A.

Columns and Forum Roberto Togneri-The University of Western Australia

e-Newsletter

Ervin Sejdic–University of Pittsburgh, U.S.A. Social Media and Outreach

Tiago Henrique Falk—INRS, Canada Special Initiatives

Andres Kwasinski-Rochester Institute of Technology, U.S.A.

EDITORIAL BOARD

Daniel Bliss-Arizona State University, USA

- Danijela Cabric-University of California, Los Angeles Volkan Cevher—École polytechnique fédérale de
- Lausanne, Switzerland Mrityunjoy Chakraborty—Indian Institute of

Technology, Kharagpur, India George Chrisikos—Qualcomm, Inc., U.S.A.

Alfonso Farina—Leonardo S.p.A., Italy Clem Karl-Boston University, U.S.A.

C.-C. Jay Kuo-University of Southern California, USÀ

Erik Larsson-Linköping University, Sweden

David Love—Purdue University, USA

Maria G. Martini-Kingston University, U.K. Helen Meng-City University of Hong Kong,

- Hong Kong SAR of China Meinard Mueller—Friedrich-Alexander Universität
- Erlangen-Nürnberg, Germany

Douglas O'Shaughnessy-INRS Universite de Recherche, Canada

Osvaldo Simeone-Kings College London, U.K. Milica Stojanovic—Northeastern University, USA Ananthram Swami, Army Research Labs, U.S.A. Jong Chul Ye-KAIST, South Korea Qing Zhao-Cornell University, USA

ASSOCIATE EDITORS—COLUMNS AND FORUM

Ivan Bajic—Simon Fraser University, Canada Balázs Bank-Budapest University of Technology and Economics, Hungary

Ching-Te Chiu-National Tsing Hua University, Taiwan

Panayiotis (Panos) Georgiou-University of Southern California, U.S.A.

Hana Godrich-Rutgers University, U.S.A. Rodrigo Capobianco Guido—São Paulo

State University, Brazil

Xiaodong He-Microsoft Research

IEEE Signal Processing Magazine

Yuan-Hao Huang-National Tsing Hua University, Taiwan Euee Seon Jang-Hanyang University, Republic of Korea

Danilo Mandic-Imperial College, U.K. Vishal Patel-Rutgers University, U.S.A. Fatih Porikli-Australian National University Shantanu Rane—PARC, U.S.A. Christian Ritz-University of Wollongong, Australia Changshui Zhang-Tsinghua University, China

ASSOCIATE EDITORS—e-NEWSLETTER

Csaba Benedek-Hungarian Academy of Sciences, Hungary Yang Li-Harbin Institute of Technology, China Yuhong Liu-Penn State University at Altoona, U.S.A. Andreas Merentitis—University of Athens, Greece

Michael Muma-TU Darmstadt, Germany Xiaorong Zhang-San Francisco State University, USA

ASSOCIATE EDITOR—SOCIAL MEDIA/OUTREACH

Guijin Wang-Tsinghua University, China

IEEE SIGNAL PROCESSING SOCIETY

Ali Sayed-President Ahmed Tewfik-President-Elect Fernando Pereira-Vice President, Conferences Nikos D. Sidiropoulos-Vice President, Membership Sergio Theodoridis-Vice President, Publications Walter Kellerman–Vice President, Technical Directions

IEEE SIGNAL PROCESSING SOCIETY STAFF

William Colacchio-Senior Manager, Publications and Education Strategy and Services Rebecca Wollman-Publications Administrator

IEEE PERIODICALS MAGAZINES DEPARTMENT

Jessica Welsh, Managing Editor Geraldine Krolin-Taylor, Senior Managing Editor Janet Dudar, Senior Art Director Gail A. Schnitzer, Associate Art Director Theresa L. Smith, Production Coordinator Mark David, Director, Business Development -Media & Advertising Felicia Spagnoli, Advertising Production Manager Peter M. Tuohy, Production Director Kevin Lisankie, Editorial Services Director Dawn M. Melley, Staff Director,

Publishing Operations

Digital Object Identifier 10.1109/MSP.2018.2849041

SCOPE: IEEE Signal Processing Magazine publishes tutorial-style articles on signal processing research and applications as well as columns and forums on issues of interest. Its coverage ranges from fundamental principles to practical implementation, reflecting the multidimensional facets of interests and concerns of the community. Its mission is to bring up-to-date, emerging and active technical developments, issues, and events to the research, educational, and professional communities. It is also the main Society communication platform addressing important issues concerning all members.