



# Contents

Volume 34 | Number 5 | September 2017

# **SPECIAL SECTION**

## ADVANCES IN SIGNAL PROCESSING FOR GLOBAL NAVIGATION SATELLITE SYSTEMS

12 FROM THE GUEST EDITORS

Pau Closas, Marco Luise, José-Ángel Ávila-Rodríguez, Christopher Hegarty, and Jiyun Lee

16 SIGNAL MULTIPLEXING TECHNIQUES FOR GNSSs

Zheng Yao and Mingquan Lu

27 SIGNAL STRUCTURE-BASED AUTHENTICATION FOR CIVIL GNSSs

Davide Margaria, Beatrice Motella, Marco Anghileri, Jean-Jacques Floch, Ignacio Fernández-Hernández, and Matteo Paonni

38 UNAMBIGUOUS TECHNIQUES IN MODERNIZED GNSS SIGNALS

Elena Simona Lohan, Diego Alonso de Diego, José A. López-Salcedo, Gonzalo Seco-Granados, Pedro Boto, and Pedro Fernandes





## ON THE COVER

This special issue of *IEEE Signal Processing Magazine* begins by addressing the design of special global navigation satellite system signals and continues with the discussion of effective techniques for receiver performance enhancement. It finishes with the analysis of some vulnerabilities.

COVER IMAGE: @ISTOCKPHOTO.COM/BLACKJACK3D

53 PROCESSING COST OF DOPPLER SEARCH IN GNSS SIGNAL ACQUISITION

Sana U. Qaisar and Craig R. Benson

59 HIGH SENSITIVITY AND FAST ACQUISITION SIGNAL PROCESSING TECHNIQUES FOR GNSS RECEIVERS

Seung-Hyun Kong

72 DIRECT POSITION ESTIMATION OF GNSS RECEIVERS

Pau Closas and Adrià Gusi-Amigó

85 TIME-FREQUENCY ANALYSIS FOR GNSSs

Moeness G. Amin, Daniele Borio, Yimin D. Zhang, and Lorenzo Galleani

## 96 MONITORING AND MITIGATION OF IONOSPHERIC ANOMALIES FOR GNSS-BASED SAFETY CRITICAL SYSTEMS

Jiyun Lee, Y.T. Jade Morton, Jinsil Lee, Hee-Seung Moon, and Jiwon Seo

## 

Zaher (Zak) M. Kassas, Joe Khalife, Kimia Shamaei, and Joshua Morales

## **FEATURES**

125 THE MICROSOFT INDOOR LOCALIZATION COMPETITION

Dimitrios Lymberopoulos and Jie Liu

141 SIGNAL PROCESSING FOR GIGABIT-RATE WIRELINE COMMUNICATIONS

S.M. Zafaruddin, Itsik Bergel, and Amir Leshem



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 copies: IEEE Members US\$20.00 (first copy only), nonmembers US\$241.00 per copy. Copyright and Reprint Permissions: 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 fee indicated in the code is paid through the Copyright Clearance Center, 222 Rosewood Drive, Darwers, MA 01923 USA; 2) pre-1978 articles without fee. Instructors are permitted to photocopy isolated articles for noncommercial classroom use without fee. For all other copying, reprint, or republication permission, write to IEEE Service Center, 445 Hose Lane, Piscataway, NJ 08854 USA. Capadian GST #125634188

Printed in the U.S.A.

Printed in the U.S.A.

## Society News

Election of Regional Directors-at-Large and Members-at-Large

## **Special Reports**

Building the Foundation for "Generation Robot" John Edwards

## Lecture Notes

High Dynamic Range Imaging Technology Alessandro Artusi, Thomas Richter, Touradi Ebrahimi, and Rafał K. Mantiuk

Image Restoration: From Sparse and Low-Rank Priors to Deep Priors Lei Zhang and Wangmeng Zuo

## Tips & Tricks

An Easy and Efficient Method for Synthesizing Two-Dimensional Finite Impulse Response Filters with Improved Selectivity Peter S. Apostolov, Borislav P. Yurukov, and Alexey K. Stefanov

The Sliding Windowed Infinite Fourier Transform Logan L. Grado, Matthew D. Johnson, and Theoden I. Netoff

#### 196 Perspectives

Signal Processing and Machine Learning for Mental Health Research and Clinical Applications Daniel Bone, Chi-Chun Lee, Theodora Chaspari, James Gibson, and Shrikanth Narayanan

## **DEPARTMENTS**

## From the Editor

Cameras, Music, and Synergy in Signal Processing Min Wu

## President's Message

Careers in Signal Processing: A Diverse Field Impacting the Future Rabab Ward

#### COVER 3 Dates Ahead



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

## **IEEE Signal Processing Magazine**

#### **EDITOR-IN-CHIEF**

Min Wu-University of Maryland, College Park U.S.A.

## **AREA EDITORS**

## Feature Articles

Shuguang Robert Cui—Texas A&M University, U.S.A.

## Special Issues

Douglas O'Shaughnessy—INRS, Canada

## Columns and Forum

Kenneth Lam—Hong Kong Polytechnic University, Hong Kong SAR of China

## e-Newsletter

Ervin Sejdic-University of Pittsburgh, U.S.A.

## Social Media and Outreach

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

## **EDITORIAL BOARD**

Mrityunjoy Chakraborty - Indian Institute of Technology, Kharagpur, India

George Chrisikos - Qualcomm, Inc., U.S.A.

Alfonso Farina - Leonardo S.p.A., Italy Mounir Ghogho-University of Leeds, U.K.

Lina Karam-Arizona State University, U.S.A. C.-C. Jay Kuo - University of Southern California, U.S.A

Sven Loncărić - University of Zagreb, Croatia Brian Lovell - University of Queensland, Australia Jian Lu-Qihoo 360, China

Henrique (Rico) Malvar-Microsoft Research, U.S.A.

Yi Ma-ShanghaiTech University, China Stephen McLaughlin-Heriot-Watt University, Scotland

Athina Petropulu—Rutgers University, U.S.A.

Peter Ramadge—Princeton University, USA

Shigeki Sagayama—Meiji University, Japan Erchin Serpedin-Texas A&M University,

Shihab Shamma—University of Maryland,

Vahid Tarokh—Harvard University, U.S.A. Wade Trappe-Rutgers University, U.S.A. Gregory Wornell—Massachusetts Institute of Technology, U.S.A.

Dapeng Wu-University of Florida, U.S.A.

## ASSOCIATE EDITORS—COLUMNS AND FORUM

Ivan Bajic—Simon Fraser University, Canada

Rodrigo Capobianco Guido-São Paulo State University, Brazil Ching-Te Chiu-National Tsing Hua University,

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

Hana Godrich-Rutgers University, U.S.A. Xiaodong He-Microsoft Research

Danilo Mandic-Imperial College, U.K. Aleksandra Mojsilovic-

IBM T.J. Watson Research Center Vishal Patel-Rutgers University, U.S.A. Fatih Porikli-MERL

Shantanu Rane—PARC, U.S.A.

Saeid Sanei-University of Surrey, U.K. Roberto Togneri - The University of

Western Australia

Alessandro Vinciarelli — IDIAP-EPFL

Azadeh Vosoughi—University of Central Florida Stefan Winkler—UIUC/ADSC, Singapore

Changshui Zhang — Tsinghua University, China

## ASSOCIATE EDITORS—e-NEWSLETTER

Csaba Benedek—Hungarian Academy of Sciences, Hungary

Paolo Braca—NATO Science and Technology Organization, Italy

Quan Ding-University of California, San Francisco, U.S.A.

Pierluigi Failla—Compass Inc, New York, U.S.A.

Marco Guerriero—General Electric Research, U.S.A.

Yang Li-Harbin Institute of Technology, China Yuhong Liu-Penn State University at Altoona, U.S.A.

Andreas Merentitis—University of Athens,

Michael Muma-TU Darmstadt, Germany Xiaorong Zhang - San Francisco State University, U.S.A.

## ASSOCIATE EDITOR—SOCIAL MEDIA/OUTREACH

Guijin Wang-Tsinghua University, China

## **IEEE SIGNAL PROCESSING SOCIETY**

Rabab Ward-President

Ali Sayed-President-Elect

Carlo S. Regazzoni - Vice President, Conferences

Nikos D. Sidiropoulos—Vice President, Membership

Thrasyvoulos (Thrasos) N. Pappas — Vice President, Publications

Walter Kellerman-Vice President, Technical Directions

## **IEEE SIGNAL PROCESSING SOCIETY STAFF**

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

Dawn M. Melley, Editorial Director

Peter M. Tuohy, Production Director

Fran Zappulla, Staff Director, Publishing Operations

Digital Object Identifier 10.1109/MSP.2017.2713742

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.