# PROCEEDINGS OF SPIE

# Radar Sensor Technology XXIII

Kenneth I. Ranney Armin Doerry Editors

15–17 April 2019 Baltimore, Maryland, United States

Sponsored and Published by SPIE

**Volume 11003** 

Proceedings of SPIE 0277-786X, V. 11003

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

Radar Sensor Technology XXIII, edited by Kenneth I. Ranney, Armin Doerry, Proc. of SPIE Vol. 11003, 1100301 · © 2019 SPIE · CCC code: 0277-786X/19/\$18 · doi: 10.1117/12.2537087

The papers in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. Additional papers and presentation recordings may be available online in the SPIE Digital Library at SPIEDigitalLibrary.org.

The papers reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from these proceedings:

Author(s), "Title of Paper," in *Radar Sensor Technology XXIII*, edited by Kenneth I. Ranney, Armin Doerry, Proceedings of SPIE Vol. 11003 (SPIE, Bellingham, WA, 2019) Seven-digit Article CID Number.

ISSN: 0277-786X

ISSN: 1996-756X (electronic)

ISBN: 9781510626713

ISBN: 9781510626720 (electronic)

Published by

SPIE

P.O. Box 10, Bellingham, Washington 98227-0010 USA Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445

SPIE.org

Copyright © 2019, Society of Photo-Optical Instrumentation Engineers.

Copying of material in this book for internal or personal use, or for the internal or personal use of specific clients, beyond the fair use provisions granted by the U.S. Copyright Law is authorized by SPIE subject to payment of copying fees. The Transactional Reporting Service base fee for this volume is \$18.00 per article (or portion thereof), which should be paid directly to the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923. Payment may also be made electronically through CCC Online at copyright.com. Other copying for republication, resale, advertising or promotion, or any form of systematic or multiple reproduction of any material in this book is prohibited except with permission in writing from the publisher. The CCC fee code is 0277-786X/19/\$18.00.

Printed in the United States of America by Curran Associates, Inc., under license from SPIE.

Publication of record for individual papers is online in the SPIE Digital Library.



**Paper Numbering:** Proceedings of SPIE follow an e-First publication model. A unique citation identifier (CID) number is assigned to each article at the time of publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online and print versions of the publication. SPIE uses a seven-digit CID article numbering system structured as follows:

- The first five digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B ... 0Z, followed by 10-1Z, 20-2Z, etc. The CID Number appears on each page of the manuscript.

### **Contents**

vii **Authors** Conference Committee ix SYSTEMS I 11003 03 FM radio passive multistatic radar using data fusion [11003-2] 11003 04 A comparison of ground-based and airborne SAR systems for the detection of landmines, UXO, and IEDs [11003-3] 11003 05 Imaging of buried targets using UAV-based, ground penetrating, synthetic aperture radar [11003-4] SYSTEM DEVELOPMENT 11003 06 Investigation of airborne synthetic aperture radar parameters for buried target detection [11003-5] 11003 07 Simultaneous multi-mission (SMM) in ground and airborne radars: system development tools and enabling technologies [11003-6] 11003 08 Robust decision making method for adaptive ordered-statistics CFAR technique using information elasticity [11003-7] 11003 09 Physical-model-aided antenna pattern calibration for flight inspection [11003-8] 11003 0A Cost function design for modeling information overload in radar systems [11003-9] **NON-LINEAR RADAR** 11003 OF Harmonic nonlinear radar: from benchtop experimentation to short-range wireless data **collection** [11003-15] 11003 0G High resolution harmonic radar imaging for safety and security applications [11003-16] **POLARIZATION** 11003 OH Performance effect of unintended polarization on clutter attenuation [11003-17]

11003 01	Empirical observations from analysis of coherency matrices of 4-look SIR-C data [11003-18]
	NOISE RADAR
11003 OK	A formulation of noise operators and their applications [11003-20]
11003 OL	Kicked rotor quantum chaos (KRQC) for radar noise waveform design [11003-21]
11003 OM	Design of spectrally adaptive noise radar waveforms [11003-22]
	DOPPLER AND MICRO-DOPPLER
11003 ON	On minimum detectable velocity [11003-23]
11003 OP	Detection of vibrating objects in SAR images [11003-25]
11003 0Q	Abnormal gait detection and classification using micro-Doppler radar signatures [11003-26]
11003 OR	Simulation of the dynamic radar cross section variations of a human emulator calibration target for through-wall and through-rubble radar [11003-27]
11003 OS	Millimeter-wave radar micro-Doppler feature extraction of consumer drones and birds for target discrimination [11003-28]
	PROCESSING I: PARALLEL PROCESSING AND MACHINE LEARNING
11003 OU	A method for accurate, highly parallelizable SAR image reconstruction without interpolation [11003-29]
11003 OV	Quantized wavelet scattering networks for signal classification [11003-31]
11003 OW	Convergence analysis of the CNN algorithm in target recognition using SAR images [11003-32]
11003 OX	Further investigation of the application of deep learning for electromagnetic simulation prediction $[11003\text{-}33]$
	SYSTEM HARDWARE
11003 0Y	Total reliability of radar systems: incorporating component degradation effects in operational reliability [11003-34]

# SYSTEMS II 11003 10 Non-cooperative emitter classification and localization with vector sensing and machine learning in indoor environments [11003-36] 11003 11 Satellite radar interferometry using micro-retroreflective arrays [11003-37] 11003 12 Challenges in very high resolution imaging of satellites and objects in space [11003-38] 11003 14 Applications of the Aharonov Ansatz to antenna theory: Part III [11003-40] **APPLICATIONS** 11003 16 Application of microwave noiselets for nondestructive testing of unidirectional carbon fiber reinforced polymers [11003-42] 11003 17 Electromagnetic response changes of unidirectional carbon fiber-reinforced polymer circuitanalog absorbers due to post-processing impact damage [11003-43] 11003 18 Comparing stochastic and Markov decision process approaches for predicting radio frequency interference [11003-44] PROCESSING II: WAVEFORM DESIGN 11003 19 Channel-hopping blind rendezvous for cognitive radio networks using channel occupancy **prediction** [11003-45] 11003 1A Modified transmitted reference technique for multi-resolution radar timing and synchronization [11003-46] 11003 1B Polynomial chirplet approach for frequency modulation signal separation and classification [11003-47] 11003 1C A compound Gaussian-based waveform design approach for enhanced target detection in multistatic radar imaging [11003-48] MILLIMETRE WAVE RADAR: JOINT SESSION WITH CONFERENCES 10994 AND 11003 11003 1D Millimeter-wave airborne radar for learning and education (MARBLE): an undergraduate student mission [11003-49]

#### **POSTER SESSION**

11003 1E	Analyzing receiver bandwidth for near-range ultra-wideband pulse compression imaging radar systems [11003-50]
11003 1F	Radiometric calibration of range-Doppler radar data [11003-51]
11003 1G	Implementation of practically realizable micro-Doppler experiment and real-time micro-Doppler feature extraction algorithm [11003-52]
11003 1H	Design and analysis of the PLL-based synthesizer for UAV detection radar applications [11003-53]
11003 11	Issues associated with radar applications on software defined radios [11003-54]

#### **Authors**

Numbers in the index correspond to the last two digits of the seven-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first five digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

Addison, Stephen R., 0K Anger, S., 12 Atwood, Thomas, 0P Bähnemann, Rik, 04 Bajic, Ivan, 0U Bassett, Christopher, 07 Bickel, D. L., 0H, 0N Bischeltsrieder, Florian, 0G Blount, Clay B., 0X Buehrer, R. Michael, 18 Burr, Ralf, 04

Dill, S., 12 Doerry, Armin W., 0H, 0N, 0P, 1F

Dogaru, Traian V., 05, 06 Dunkel, Ralf, 0P Dyer, John, 09, 1D Fox, Maxine R., 0V Fusselman, Jakob, 1D Gallagher, Kyle, 1I Geaga, Jorge V., 0I Gedin, Kahlil R., 14 Gilliam, Matthew, 09, 1D Gray, John E., 0K, 14 Hall, Donald L., 0Q, 10 Handel, Clark F., 03 Hayat, Majeed M., 0P

Hedden, Abigail, 11 Heinzel, Andreas, 04, 0G Homeyer, Cameron, 1D Idriss, Zacharie, 1C Jendzurski, John R., 0R Jenkins, David M., 10, 1A Jiroušek, Matthias, 0G, 12

Kelly, Colin D., 06, 1E Kelly, Keith, 07 Kim, Taeyoung, 0R Kovarskiy, Jacob A., 18 Kozy, Mark, 18

Lee, Hua-Chin, 1H Lenzing, Erik H., 10 Li, Bing C., 0L, 1B Liao, DaHan, 05 Lipski, Michael V., 19 Liu, Andrew Z., 08 Martinez, Emilio, 11

Martone, Anthony F., 18 Mazzaro, Gregory J., 0F

Moore, B. David, 11

Narayanan, Ram M., 03, 06, 08, 0A, 0M, 0Q, 0R, 0V, 0Y, 10, 16, 17, 18, 19, 1A, 1C, 1E

Navagato, Marc D., 16 Necsoiu, Marius, 11 O'Donnell, Joseph C., 17 Ou Yang, Liang-Yu, 1G Paulter, Nicholas G., 0R Peichl, Markus, 04, 0G, 12 Pérez, Francisco, 0P Phelan, Brian R., 05, 06, 1E Pici, Caden J., 0M

Price, Carey D., 0X Price, Stanton R., 0X Price, Steven R., 0X Qiao, Zhijun, 0W Rahman, Samiur, 0S Raj, Raghu G., 0V, 1C

Rangaswamy, Muralidhar, 08, 0A Ranney, Kenneth I., 11

Ridder, Tyler D., OQ, OY Riley, Elliot J., 17 Robertson, Duncan A., OS Salazar Cerreno, Jorge, 07 Santhanam, Balu, OP Schartel, Markus, 04 Schreiber, Eric, 04, OG

Sherbondy, Kelly D., 06, 0F, 18, 1E

Singerman, Paul G., 0A Thornton, Charles, 18 Tsai, Ming-Fa, 1G Tsao, Ya-Lan, 1H

Waldschmidt, Christian, 04 Wang, Chao-Shiun, 1H Young, Jason R., 1A

Zhang, Yan Rockee, 07, 09, 1D

Zou, Ligang, 0W

## **Conference Committee**

Symposium Chairs

Jay Kumler, JENOPTIK Optical Systems, LLC (United States)
Ruth L. Moser, Air Force Research Laboratory (United States)

Symposium Co-chair

**John M. Pellegrino**, Georgia Institute of Technology (United States)

Conference Chairs

**Kenneth I. Ranney**, U.S. Army Research Laboratory (United States) **Armin Doerry**, Sandia National Laboratories (United States)

Conference Program Committee

Fauzia Ahmad, Temple University (United States)

Moeness G. Amin, Villanova University (United States)

**Joseph C. Deroba**, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States)

Mark Govoni, U.S. Army Research Laboratory (United States)

**John E. Gray**, Naval Surface Warfare Center Dahlgren Division (United States)

Majeed M. Hayat, Marquette University (United States)

Chandra Kambhamettu, University of Delaware (United States)

**Seong-Hwoon Kim**, L3 Technologies, Inc. (United States)

Marco O. Lanzagorta, U.S. Naval Research Laboratory (United States)

**Bing C. Li**, Lockheed Martin Systems Integration-Owego (United States)

Changzhi Li, Texas Tech University (United States)

Jenshan Lin, University of Florida (United States)

**Robert Linnehan**, General Atomics Aeronautical Systems, Inc. (United States)

**Ronald D. Lipps**, U.S. Naval Research Laboratory (United States)

**David G. Long**, Brigham Young University (United States)

**Neeraj Magotra**, Western New England University (United States)

**Anthony F. Martone**, U.S. Army Research Laboratory (United States)

**Gregory J. Mazzaro**, The Citadel-The Military College of South Carolina (United States)

Ram M. Narayanan, The Pennsylvania State University (United States)

Marius Necsoiu, Southwest Research Institute (United States)

Lam H. Nguyen, U.S. Army Research Laboratory (United States)

**Hector A. Ochoa**, The University of Texas at Tyler (United States)

Thomas J. Pizzillo, U.S. Naval Research Laboratory (United States)
Zhijun G. Qiao, The University of Texas-Pan American (United States)
Ann Marie Raynal, Sandia National Laboratories (United States)
Jerry Silvious, U.S. Army Research Laboratory (United States)
David Tahmoush, U.S. Naval Research Laboratory (United States)
Russell Vela, Air Force Research Laboratory (United States)
Frank Yakos, Consultant (United States)
Yan Rockee Zhang, The University of Oklahoma (United States)
Ruolin Zhou, Western New England University (United States)

#### Session Chairs

1 Systems I

Lam H. Nguyen, U.S. Army Research Laboratory (United States)

2 System Development

**Gregory J. Mazzaro**, The Citadel-The Military College of South Carolina (United States)

- 3 Radar Research at Government Labs Armin W. Doerry, Sandia National Laboratories (United States) Kenneth I. Ranney, U.S. Army Research Laboratory (United States)
- 4 Non-Linear Radar **Brian R. Phelan**, U.S. Army Research Laboratory (United States)
- Polarization
   Brian R. Phelan, U.S. Army Research Laboratory (United States)
- The History of Noise

  John E. Gray, Naval Surface Warfare Center Dahlgren Division

  (United States)
- Noise Radar
   Ram M. Narayanan, The Pennsylvania State University (United States)
- Doppler and Micro-Doppler
   Ann Marie Raynal, Sandia National Laboratories (United States)
- 9 Processing I: Parallel Processing and Machine Learning Yan Rockee Zhang, The University of Oklahoma (United States)
- System HardwareSeong-Hwoon Kim, L3 Technologies, Inc. (United States)

- Systems IIBing C. Li, Lockheed Martin Systems Integration-Owego (United States)
- 12 Applications **Seong-Hwoon Kim**, L3 Technologies, Inc. (United States)
- 13 Processing II: Waveform Design

  Ram M. Narayanan, The Pennsylvania State University (United States)
- 14 Millimetre Wave Radar: Joint Session with Conferences 10994 and 11003
  - David A. Wikner, U.S. Army Research Laboratory (United States)