

PROCEEDINGS OF SPIE

Signal and Data Processing of Small Targets 2009

**Oliver E. Drummond
Richard D. Teichgraeber**
Editors

**4–6 August 2009
San Diego, California, United States**

Sponsored and Published by
SPIE

Volume 7445

Proceedings of SPIE, 0277-786X, v. 7445

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

The papers included 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. The papers published in these proceedings 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 this book:

Author(s), "Title of Paper," in *Signal and Data Processing of Small Targets 2009*, edited by Oliver E. Drummond, Richard D. Teichgräber, Proceedings of SPIE Vol. 7445 (SPIE, Bellingham, WA, 2009) Article CID Number.

ISSN 0277-786X
ISBN 9780819477354

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 © 2009, 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/09/\$18.00.

Printed in the United States of America.

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

The logo for SPIE Digital Library features the word "SPIE" in a bold, sans-serif font above the words "Digital Library" in a smaller, similar font. To the right of the text is a stylized graphic consisting of three vertical bars of increasing height, resembling a bar chart or a signal waveform.

SPIDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print and on CD-ROM. Papers are published as they are submitted and meet publication criteria. A unique, consistent, permanent citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- The first four 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. The complete citation is used on the first page, and an abbreviated version on subsequent pages. Numbers in the index correspond to the last two digits of the six-digit CID number.

Contents

vii	<i>Conference Committee</i>
ix	<i>Introduction</i>

SESSION 1 SMALL TARGET SIGNAL AND DATA PROCESSING

- 7445 02 **MIMO vs. multistatic radars for target localization** [7445-01]
A. A. Gorji, R. Tharmarasa, T. Kirubarajan, McMaster Univ. (Canada)
- 7445 03 **Interacting multiple model forward filtering and backward smoothing for maneuvering target tracking** [7445-03]
N. Nandakumaran, S. Sutharsan, R. Tharmarasa, McMaster Univ. (Canada); T. Lang, General Dynamics Canada Ltd. (Canada); M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)
- 7445 04 **Ultra-scale vehicle tracking in low spatial resolution and low frame-rate overhead video** [7445-04]
C. J. Carrano, Lawrence Livermore National Lab. (United States)
- 7445 05 **Event-based characterization and simulation of sea clutter** [7445-05]
M. K. McDonald, Defence Research and Development Canada (Canada); D. Dunne, McMaster Univ. (Canada); A. Damini, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)
- 7445 06 **Resolving transmitter-of-opportunity origin uncertainty in passive coherent location systems** [7445-07]
R. Tharmarasa, N. Nandakumaran, McMaster Univ. (Canada); M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)

SESSION 2 SIGNAL AND EXTENDED OBJECT PROCESSING

- 7445 07 **Noise resistant algorithm for radar images recognition and classification** [7445-08]
V. Zeljković, Q. Li, R. Vincelette, C. Tameze, F. Liu, Delaware State Univ. (United States)
- 7445 08 **Context-aware tracking of small targets in video** [7445-09]
J. Fan, J. Xu, Y. Wu, Northwestern Univ. (United States)
- 7445 09 **Detection of suspicious activity using incremental outlier detection algorithms** [7445-10]
D. Pokrajac, N. Reljin, N. Pejicic, T. Vance, S. McDaniel, Delaware State Univ. (United States); A. Lazarevic, United Technologies Research Ctr. (United States); H. J. Chang, J. Y. Choi, Seoul National Univ. (Korea, Republic of); R. Mieziako, Lockheed Martin (United States)
- 7445 0A **Featured points method of amplitude recovery** [7445-12]
Q. Li, Z. Zeng, J. Sun, F. Liu, Delaware State Univ. (United States)

- 7445 0B **Comparison of extended and unscented Kalman, particle, and smooth variable structure filters on a bearing-only target tracking problem** [7445-41]
S. A. Gadsden, D. Dunne, S. R. Habibi, T. Kirubarajan, McMaster Univ. (Canada)
- 7445 0C **Extraction, categorization, and unusual motion signaling of small moving objects** [7445-14]
L. Kovács, Á. Utasi, T. Szirányi, Computer and Automation Research Institute (Hungary)

SESSION 3 PROBABILITY HYPOTHESIS DENSITY PROCESSING

- 7445 0D **Assignment-based particle labeling for PHD particle filter** [7445-15]
D. G. Danu, McMaster Univ. (Canada); T. Lang, General Dynamics Canada Ltd. (Canada); T. Kirubarajan, McMaster Univ. (Canada)
- 7445 0E **CPHD filters for superpositional sensors** [7445-16]
R. Mahler, Lockheed Martin MS2 Tactical Systems (United States)
- 7445 0F **SMC-PHD-based multi-target tracking with reduced peak extraction** [7445-17]
D. Dunne, General Dynamics Canada Ltd. (Canada) and McMaster Univ. (Canada); R. Tharmarasa, McMaster Univ. (Canada); T. Lang, General Dynamics Canada Ltd. (Canada); T. Kirubarajan, McMaster Univ. (Canada)
- 7445 0G **Further analysis of the track repulsion effect in automatic tracking** [7445-36]
S. Coraluppi, C. Carthel, NATO Undersea Research Ctr. (Italy); P. Willett, Univ. of Connecticut (United States); T. Luginbuhl, Naval Undersea Warfare Ctr. (United States)
- 7445 0H **Distributed tracking with probability hypothesis density filters using efficient measurement encoding** [7445-19]
A. Aravinthan, R. Tharmarasa, McMaster Univ. (Canada); T. Lang, General Dynamics Canada Ltd. (Canada); M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)
- 7445 0I **Second-generation PHD/CPHD filters and multitarget calculus** [7445-20]
R. Mahler, Lockheed Martin MS2 Tactical Systems (United States)
- 7445 0J **Rao-Blackwellised approximate conditional mean probability hypothesis density filtering** [7445-21]
N. Nandakumaran, S. Sutharsan, R. Tharmarasa, McMaster Univ. (Canada); T. Lang, General Dynamics Canada Ltd. (Canada); T. Kirubarajan, McMaster Univ. (Canada)

SESSION 4 PROCESSING WITH MULTIPLE SENSOR DATA

- 7445 0K **Multiple-target tracking via kinematics, shape, and appearance-based data association** [7445-22]
S. Wu, Y. Tan, S. Das, C. Broaddus, M.-Y. Chiu, Sarnoff Corp. (United States)
- 7445 0L **Tracking move-stop-move targets with state-dependent mode transition probabilities** [7445-47]
S. Zhang, Y. Bar-Shalom, Univ. of Connecticut (United States)

- 7445 OM **Target tracking for multistatic radar with transmitter uncertainty** [7445-24]
S. Choi, C. R. Berger, D. Crouse, P. Willett, S. Zhou, Univ. of Connecticut (United States)
- 7445 ON **Track covariance consistency compensation performance** [7445-25]
O. E. Drummond, D. Dana-Bashian, CyberRnD, Inc. (United States)
- 7445 OO **Network-centric angle only tracking** [7445-27]
J. Yosinski, N. Coult, R. Paffenroth, Numerica Corp. (United States)
- 7445 OP **Sensor bias estimation in the presence of data association uncertainty** [7445-28]
D. F. Crouse, Y. Bar-Shalom, P. Willett, Univ. of Connecticut (United States)

SESSION 5 SMALL TARGET TRACKING

- 7445 OQ **A performance comparison of nonlinear filtering techniques based on recorded radar datasets** [7445-29]
B. Balaji, Z. Ding, Defence Research and Development Canada (Canada)
- 7445 OR **Nonlinear filters with particle flow** [7445-30]
F. Daum, J. Huang, Raytheon Co. (United States)
- 7445 OS **Integration of a road network into a radar ground moving target tracking (GMTT) system and its performance evaluation** [7445-31]
S. Blackman, K. Fong, D. E. Carroll, J. Lancaster, Raytheon Co. (United States); R. Dempster, Independent Contractor (United States)
- 7445 OT **Design of an adaptive passive collision warning system for UAVs** [7445-32]
R. W. Osborne III, Y. Bar-Shalom, P. Willett, Univ. of Connecticut (United States); G. Baker, MilSys Technologies, LLC (United States)
- 7445 OU **Unbiased Kalman filter using converted measurements: revisit** [7445-38]
W. Mei, Shijiazhuang Mechanical Engineering College (China); Y. Bar-Shalom, Univ. of Connecticut (United States)
- 7445 OV **Seventeen dubious methods to approximate the gradient for nonlinear filters with particle flow** [7445-34]
F. Daum, J. Huang, M. Krichman, T. Kohen, Raytheon Co. (United States)

SESSION 6 SIGNAL AND DATA PROCESSING

- 7445 OW **Estimation of laser system pointing parameters using a near-Gaussian irradiance profile** [7445-37]
S. Aeddy, D. K. Borah, D. G. Voelz, X. Xiao, New Mexico State Univ. (United States)
- 7445 OX **Integrated clutter estimation and target tracking using Poisson point process** [7445-39]
X. Chen, R. Thamarasa, T. Kirubarajan, McMaster Univ. (Canada); M. Pelletier, ICx Radar Systems (Canada)
- 7445 OY **Recursive TBM method for target classification** [7445-40]
G. Shan, W. Mei, Y. Cheng, Shijiazhuang Mechanical Engineering College (China)

- 7445 0Z **Multipath-assisted multitarget tracking using multiframe assignment** [7445-42]
M. Subramaniam, R. Tharmarasa, McMaster Univ. (Canada); M. Pelletier, ICx Radar Systems (Canada); T. Kirubarajan, McMaster Univ. (Canada)
- 7445 10 **Segmentation of suspicious objects in an x-ray image using automated region filling approach** [7445-43]
K. Fu, C. Guest, P. Das, Univ. of California, San Diego (United States)
- 7445 11 **EM-based Gaussian mixture model estimation for GMTI-based tracking using speedboat data** [7445-44]
D. Akselrod, McMaster Univ. (Canada); M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)
- 7445 12 **Feasibility of using transmitters of opportunity for precision multitarget tracking** [7445-45]
N. Nandakumaran, R. Tharmarasa, McMaster Univ. (Canada); M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)
- 7445 13 **A novel algorithm for material discrimination using a dual energy imaging system** [7445-46]
K. Fu, Univ. of California, San Diego (United States); D. Ranta, SAIC (United States); C. Guest, P. Das, Univ. of California, San Diego (United States)

Author Index

Conference Committee

Program Track Chair

Khan M. Iffekharuddin, The University of Memphis (United States)

Conference Chair

Oliver E. Drummond, Consulting Engineer (United States)

Conference Cochair

Richard D. Teichgraeber, Consultant (United States)

Program Committee

Liyi Dai, U.S. Army Research Office (United States)

Darren K. Emge, U.S. Army Edgewood Chemical Biological Center
(United States)

Charles W. Glover, Oak Ridge National Laboratory (United States)

Lawrence E. Hoff, Hoff Engineering (United States)

Denise L. Jones, U.S. Army Space and Missile Defense Command
(United States)

Rabinder N. Madan, Office of Naval Research (United States)

Steven W. Waugh, Defense Threat Reduction Agency (United States)

Session Chairs

- 1 Small Target Signal and Data Processing
Lawrence E. Hoff, Hoff Engineering (United States)
Richard D. Teichgraeber, Consultant (United States)
- 2 Signal and Extended Object Processing
Lawrence E. Hoff, Hoff Engineering (United States)
Richard D. Teichgraeber, Consultant (United States)
- 3 Probability Hypothesis Density Processing
Richard D. Teichgraeber, Consultant (United States)
Oliver E. Drummond, Consulting Engineer (United States)
- 4 Processing with Multiple Sensor Data
Rabinder N. Madan, Office of Naval Research (United States)
Oliver E. Drummond, Consulting Engineer (United States)

- 5 Small Target Tracking
Oliver E. Drummond, Consulting Engineer (United States)
Richard D. Teichgraeber, Consultant (United States)

Introduction

This was the 21st in a series of SPIE conferences to focus on signal and data processing of small targets. Most SPIE conferences are concerned with processing large targets, namely, targets large enough for traditional automatic (or assisted) target recognition (ATR) with a single frame of data. A target large enough for ATR is typically larger than a total of 100 resolution elements, for example, larger than 10 by 10 pixels. In contrast, this conference series introduced a different thrust for SPIE: processing targets smaller than 100 pixels.

This year the conference was held in San Diego after being held in Orlando the prior year. In the future, these conferences are expected to continue to be located on the east coast in the spring on even years and in San Diego in the summer on odd years. The proceedings of the prior conferences in this series in 1989 through 2008 are SPIE Volumes 1096, 1305, 1481, 1698, 1954, 2235, 2561, 2759, 3163, 3373, 3809, 4048, 4473, 4728, 5204, 5428, 5913, 6236, 6699, and 6969. A compact disk of all the papers in this series from 1989 through 2000 is available from SPIE; it is Volume 20, which is a two-disk set.

The various types of processing tasks with sensor-derived data of targets can be broadly categorized into four generic classes, as follows:

- Sensor tracking of a single (bright) target
- Image and data processing of large targets
- Signal and data processing of medium sized targets
- Signal and data processing of small targets.

Note that the size indicated in this list is in terms of the number of resolution elements or pixels. The motivation for categorizing the processing of sensor data this way is because most of the appropriate algorithms for each of these problems differ substantially from that of the others. This conference concentrates on small targets that include:

- Point source objects
- Small extended objects
- Clusters of point source and small extended objects or a threat cloud, such as a bio/chem threat.

The size of a typical point source target in the field of view is from less than one to about 20 pixels (resolution elements) wide, depending on the sensor design. Although the processing of point targets has been studied extensively, there are still many interesting challenges in this field. In contrast, the state of the art for processing small extended objects and clusters is far less mature but interest is growing.

Small targets that are not point source objects include both small extended objects and unresolved closely spaced objects, sometimes called clumps. While these small targets provide little detailed information useful for ATR, they do exhibit some shape and size information that might be useful in tracking. In addition, an extended object may at times be partially or fully obscured or may obscure rather than add to the background. The apparent size and shape of a target can differ from sensor-to-sensor and over time; this may have to be taken into account. Similarly, cluster processing offers significant advantages and challenges.

Improved sensors, increasingly demanding system requirements, processor hardware limitations, severe operating environments, efficacious countermeasures, and challenging threat scenarios drive current algorithm development. Of special interest is the ability to track low observables or in a moderate to dense population of threshold exceedances caused by clutter, false signals, or targets that are close or crossing.

There is an increasing need for improvements in “algorithm efficiency,” i.e., improved performance relative to the processor and communication resources required. A major trade in selecting algorithms for processing small targets is performance versus required processor and communications capacity. Also needed are accurate evaluations and predictions of required resources and functional performance under realistic conditions. Major improvements are needed in: multiple spectral signal processing, multiple target tracking, network centric sensor data fusion, multiple frame data association, multiple frame signal processing (such as track-before-detect), effective management of sensors, communications, and processor resources, target classification, processing of features and attributes, and the interaction between signal processing and tracking. Many of these issues are highlighted in Figure 1. In addition, needed is additional information and covariance consistency in the tracker output to the users and functions that depend on the tracker data to facilitate the improvement of their performance.

The term *fuse-before-detect* in Figure 1 refers to the combining (fusing) of raw data from multiple sensors before applying a threshold (detection) at the signal processing level. I coined this term in recognition of the increased interest in improving performance by fusing sensor data early in the processing chain. Note also in Figure 1 the possible use of track data at the signal processing level. There is a growing recognition of the importance of using all available information in every stage of the processing and hence the use of feedback.

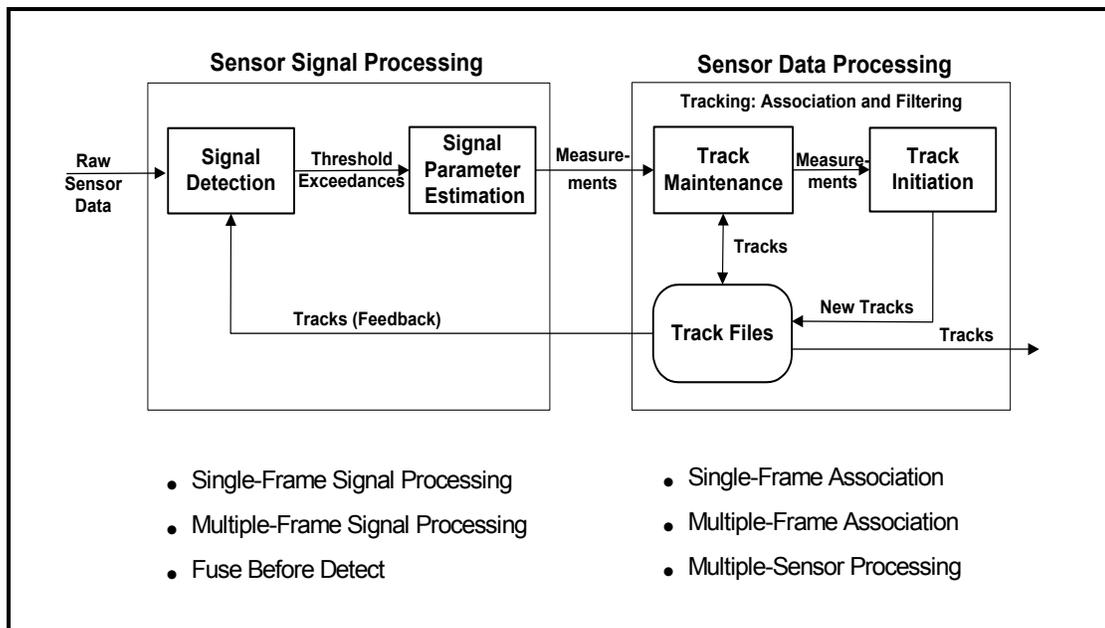


Figure 1. Sensor Signal and Data Processing

This conference has provided a forum to address these issues through discussion of algorithms and simulations for both digital signal processing and target tracking under challenging conditions, i.e., association (correlation) and filtering, including related data processing, such as sensor fusion, resource management, and target classification/typing. Of the five half-day sessions, one addressed signal-level and extended object processing, one concentrated on probability hypothesis density processing, and three addressed target tracking, sensor data fusion, and related network wide processing. The distinction between the two stages of single sensor-level processing is shown in Figure 1.

These proceedings contain a wealth of information that addresses the issues critical to practical processing under the challenging conditions outlined above. For example, important advances were presented in: chem/biodefense, novel clutter processing methods, track filter methods to accommodate non-linearities, probability hypothesis density processing, advanced distributed sensor data fusion, improved methods for tracking maneuvering targets, video tracking, processing registration biases, tracking ground targets, feature/attribute processing, and track covariance consistency processing. These techniques and others presented are strong candidates to permit high performance target tracking and classification and related processing of low observables or in an environment of moderately dense detections and with abruptly maneuvering targets. These and other innovative yet practical techniques were presented that contribute to improving algorithm efficiency for processing small targets.

Many of the experts and organizations that are making the major important advances in practical sensor signal and data processing have contributed to these proceedings. We thank the authors, session chairs, attendees, and SPIE staff for making the three-day conference such a success. They have taken part in enthusiastic discussions that generated better understanding for the application of the techniques presented and have stimulated thoughts for further improvements. Informal discussions during the coffee breaks and during lunch were especially productive, as usual. With these proceedings, the authors have extended the state of the art of analysis, algorithms, and simulations for the use of data from one or more sensors used in signal and data processing of small targets and related processing.

Oliver E. Drummond

Phone: 310-838-5300

E-Mail: Drummond@Att.Net