

PROCEEDINGS OF SPIE

Signal and Data Processing of Small Targets 2007

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

**28–30 August 2007
San Diego, California, USA**

Sponsored and Published by
SPIE

Volume 6699

Proceedings of SPIE, 0277-786X, v. 6699

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 2007*, edited by Oliver E. Drummond, Richard D. Teichgraber, Proceedings of SPIE Vol. 6699 (SPIE, Bellingham, WA, 2007) Article CID Number.

ISSN 0277-786X
ISBN 9780819468475

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 © 2007, 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/07/\$18.00.

Printed in the United States of America.

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

SPIE 
Digital Library
SPIEDigitalLibrary.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	Conference Committee
ix	Introduction

SMALL TARGET SIGNAL PROCESSING

6699 02	Beyond the resolution limit: subpixel resolution in animals and now in silicon [6699-01] M. J. Wilcox, Hyperacuity Systems (USA) and Air Force Academy (USA)
6699 03	Target detection in hyperspectral imagery using one-dimensional extended maximum average correlation height filter and Mahalanobis distance [6699-02] M. F. Islam, M. S. Alam, Univ. of South Alabama (USA)
6699 04	Performance analysis of order statistic constant false alarm rate (CFAR) detectors in generalized Rayleigh environment [6699-03] X. Xu, Intelligent Automation, Inc. (USA); R. Zheng, Univ. of Missouri, Rolla (USA); G. Chen, Intelligent Automation, Inc. (USA); E. Blasch, Air Force Research Lab. (USA)
6699 05	Tracking dim targets using integrated clutter estimation [6699-04] E. Brekke, Norwegian Univ. of Science and Technology (Norway); T. Kirubarajan, R. Tharmarasa, McMaster Univ. (Canada)
6699 06	Recognition of hidden pattern with background [6699-05] L. Kovács, T. Szirányi, MTA SZTAKI (Hungary)
6699 07	Tracking of divers in a noisy background using a bubble model [6699-06] A. Rødningsby, Norwegian Univ. of Science and Technology (Norway); Y. Bar-Shalom, Univ. of Connecticut (USA)

TARGET TRACK PROCESSING

6699 09	Modeling ballistic target motion during boost for tracking [6699-08] V. P. Jilkov, X. R. Li, J. Ru, Univ. of New Orleans (USA)
6699 0A	Theory and practical application of out of sequence measurements with results for multi-static tracking [6699-09] D. Iny, Northrop Grumman Corp. (USA)
6699 0B	The effect of various filters on covariance consistency in the presence of a nonlinear tracking problem [6699-10] L. J. Ritter, B. Weir, Johns Hopkins Univ. Applied Physics Lab. (USA)
6699 0C	Differential geometry measures of nonlinearity for filtering with nonlinear dynamic and linear measurement models [6699-11] B. F. La Scala, Univ. of Melbourne (Australia); M. Mallick, Science Applications International Corp. (USA); S. Arulampalam, Defence Science and Technology Organisation (Australia)

- 6699 0D **Monitoring of sensor covariance consistency** [6699-12]
S. S. Krigman, M. L. Smith, B. E. Tipton, MIT Lincoln Lab. (USA)
- 6699 0E **Future prospects for algorithm development of tracking related processing** [6699-13]
O. E. Drummond, CyberRnD, Inc. (USA) and Consulting Engineer (USA)
- 6699 0F **Map integration in tracking** [6699-14]
D. D. Swoorde, Univ. of California, San Diego (USA); J. E. Boyd, Cubic Defense Applications (USA); R. G. Hutchins, Naval Postgraduate School (USA)
- 6699 0G **Robust tracking for very long range radars: Part I. Algorithm comparisons** [6699-15]
X. Tian, Y. Bar-Shalom, Univ. of Connecticut (USA)

MULTIPLE-FRAME DATA ASSOCIATION

- 6699 0I **Consistent covariance estimation for PMHT** [6699-17]
W. R. Blanding, P. Willett, Univ. of Connecticut (USA); R. L. Streit, Metron, Inc. (USA); D. Dunham, Vectrxx, Inc. (USA)
- 6699 0K **Computationally efficient assignment-based algorithms for data association for tracking with angle-only sensors** [6699-19]
T. Sathyan, A. Sinha, T. Kirubarajan, McMaster Univ. (Canada)
- 6699 0L **Evaluation of a posteriori probabilities of multi-frame data association hypotheses** [6699-20]
S. Mori, C. Chong, BAE Systems, Advanced Information Technologies (USA)
- 6699 0M **Improved multitarget tracking using probability hypothesis density smoothing** [6699-21]
N. Nandakumaran, K. Punithakumar, T. Kirubarajan, McMaster Univ. (Canada)
- 6699 0N **Spline filter for nonlinear/non-Gaussian Bayesian tracking** [6699-22]
K. Punithakumar, T. Kirubarajan, McMaster Univ. (Canada)

MULTIPLE SENSORS DATA PROCESSING

- 6699 0O **Track-to-track association using informative prior associations** [6699-23]
D. G. Danu, A. Sinha, T. Kirubarajan, McMaster Univ. (Canada)
- 6699 0Q **Mitigation of biases using the Schmidt-Kalman filter** [6699-25]
R. Paffenroth, R. Novoselov, S. Danford, M. Teixeira, S. Chan, A. Poore, Numerica Corp. (USA)
- 6699 0R **Flow-rate control for managing communications in tracking and surveillance networks** [6699-26]
S. A. Miller, Numerica Corp. (USA); E. K. P. Chong, Colorado State Univ. (USA)
- 6699 0S **Feature-aided tracking with hyperspectral imagery** [6699-27]
J. Blackburn, M. Mendenhall, A. Rice, P. Shelnutt, N. Soliman, J. Vasquez, Air Force Institute of Technology (USA)

- 6699 OT **Comparison of bias removal algorithms in track-to-track association** [6699-28]
S. Mori, C. Chong, BAE Systems, Advanced Information Technologies (USA)
- 6699 OU **Improved observable operator model for joint target tracking and classification** [6699-29]
S. Sutharsan, T. Kirubarajan, McMaster Univ. (Canada)
- 6699 OV **Adaptive horizon sensor resource management: validating the core concept** [6699-30]
M. L. Hernandez, QinetiQ Ltd. (United Kingdom)

SENSOR DATA FUSION

- 6699 OW **Data fusion handoff within a federation of fusion systems** [6699-31]
P. J. Shea, B. Roskamp, Black River Systems Co. (USA)
- 6699 OY **Distributed fusion using video sensors on multiple unmanned aerial vehicles** [6699-33]
M. Mallick, Science Applications International Corp. (USA); K. C. Chang, George Mason Univ. (USA)
- 6699 OZ **Collaborative sensor management for decentralized asynchronous sensor networks** [6699-34]
R. Tharmarasa, T. Kirubarajan, McMaster Univ. (Canada)
- 6699 10 **Track-to-track association using intrinsic statistical properties** [6699-35]
P. F. Singer, Raytheon Co. (USA)
- 6699 11 **Hybrid radar signal fusion for unresolved target detection** [6699-36]
N. Nandakumaran, A. Sinha, T. Kirubarajan, McMaster Univ. (Canada)
- 6699 12 **Collaborative distributed sensor management for multitarget tracking using hierarchical Markov decision processes** [6699-37]
D. Akselrod, A. Sinha, T. Kirubarajan, McMaster Univ. (Canada)

TRACK AND FUSION PROCESSING

- 6699 13 **Optimal PHD filter for single-target detection and tracking** [6699-38]
R. Maher, Lockheed Martin MS2 Tactical Systems (USA)
- 6699 15 **Joint MAP bias estimation and data association: simulations** [6699-40]
S. Danford, B. Kragel, A. Poore, Numerica Corp. (USA)
- 6699 16 **Metrics for evaluating track covariance consistency** [6699-41]
O. E. Drummond, T. L. Ogle, CyberRnD, Inc. (USA); S. Waugh, Missile Defense Agency (USA)
- 6699 17 **The PMHT: solutions to some of its problems** [6699-42]
M. Wieneke, W. Koch, FGAN-FKIE (Germany)
- 6699 18 **Nonlinear filters with log-homotopy** [6699-43]
F. Daum, J. Huang, Raytheon (USA)

- 6699 19 **IMM/MHT tracking with an unscented particle filter with application to ground targets** [6699-44]
J. Lancaster, S. Blackman, L. Yu, Raytheon (USA)
- 6699 1A **Impact point prediction and projectile identification** [6699-45]
V. C. Ravindra, Y. Bar-Shalom, P. Willett, Univ. of Connecticut (USA)

SIGNAL AND DATA PROCESSING

- 6699 1B **Spectral unmixing of agents on surfaces for the joint contaminated surface detector (JCSD)** [6699-46]
M.-A. Slamani, T. H. Chyba, H. LaValley, ITT Corp. (USA); D. Emge, U.S. Army Edgewood Chemical Biological Ctr. (USA)
- 6699 1C **MHT tracking for crossing sonar targets** [6699-47]
P. Willett, Univ. of Connecticut (USA); T. Luginbuhl, E. Giannopoulos, Naval Undersea Warfare Ctr. (USA)
- 6699 1D **Simulation assessment of RCS-aided multiple target tracking** [6699-48]
D. T. Dunham, Vectrxx, Inc. (USA); L. M. Ehrman, W. D. Blair, Georgia Tech Research Institute (USA); S. A. Frost, Vectrxx, Inc. (USA)
- 6699 1E **Joint MAP bias estimation and data association: algorithms** [6699-49]
S. Danford, B. Kragel, A. Poore, Numerica Corp. (USA)
- 6699 1F **Bias estimation using targets of opportunity** [6699-50]
B. D. Kragel, S. Danford, S. M. Herman, A. B. Poore, Numerica Corp. (USA)
- 6699 1I **Simulation of signal and data processing for a pair of GEO IR sensors** [6699-54]
K.-H. Keil, W. Hupfer, EADS Astrium GmbH (Germany)
- 6699 1K **Robust tracking for very long-range radars: Part II. Measurement conversion and derivations** [6699-55]
X. Tian, Y. Bar-Shalom, Univ. of Connecticut (USA)

Author Index

Conference Committee

Conference Chair

Oliver E. Drummond, CyberRnD, Inc. (USA) and Consulting Engineer
(USA)

Conference Cochair

Richard D. Teichgraeber, Lockheed Martin Aeronautics Company
(USA)

Program Committee

Liyi Dai, U.S. Army Research Office (USA)
John R. Edwards, SRS Technologies (USA)
Lawrence E. Hoff, Hoff Engineering (USA)
Cornelius T. Leondes, University of California, Los Angeles (USA)
Rabinder N. Madan, Office of Naval Research (USA)
Kachesh M. Pathak, U.S. Army Space and Missile Defense Command
(USA)
Albert J. Perrella, Jr., Institute for Defense Analyses (USA)
Juan R. Vasquez, Air Force Institute of Technology (USA)
Steven Waugh, Missile Defense Agency (USA)

Session Chairs

- 1 Small Target Signal Processing
Lawrence E. Hoff, Hoff Engineering (USA)
Richard D. Teichgraeber, Lockheed Martin Aeronautics Company
(USA)
- 2 Target Track Processing
Richard D. Teichgraeber, Lockheed Martin Aeronautics Company
(USA)
- 3 Multiple-Frame Data Association
Liyi Dai, U.S. Army Research Office (USA)
Juan R. Vasquez, Air Force Institute of Technology (USA)
- 4 Multiple Sensors Data Processing
Oliver E. Drummond, CyberRnD, Inc. (USA) and Consulting Engineer
(USA)

- 5 Sensor Data Fusion
 Rabinder N. Madan, Office of Naval Research (USA)
 Juan R. Vasquez, Air Force Institute of Technology (USA)
- 6 Track and Fusion Processing
 Oliver E. Drummond, CyberRnD, Inc. (USA) and Consulting Engineer
 (USA)
 Richard D. Teichgraeber, Lockheed Martin Aeronautics Company
 (USA)

Introduction

This was the nineteenth 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 in Orlando in the spring on even years and in San Diego (or wherever the Annual Meeting is held) in the summer on odd years. The proceedings of the prior conferences in this series in 1989 through 2004 are SPIE Volumes 1096, 1305, 1481, 1698, 1954, 2235, 2561, 2759, 3163, 3373, 3809, 4048, 4473, 4728, 5204, 5428, 5913, and 6236. A compact disk of all the papers in this series from 1989 through 2000 is available from SPIE; it is Volume CDP20, 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 typically 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.

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.

Current algorithm development is driven by improved sensors, increasingly demanding system requirements, processor hardware limitations, severe operating environments, efficacious countermeasures, and challenging threat scenarios. 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 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.

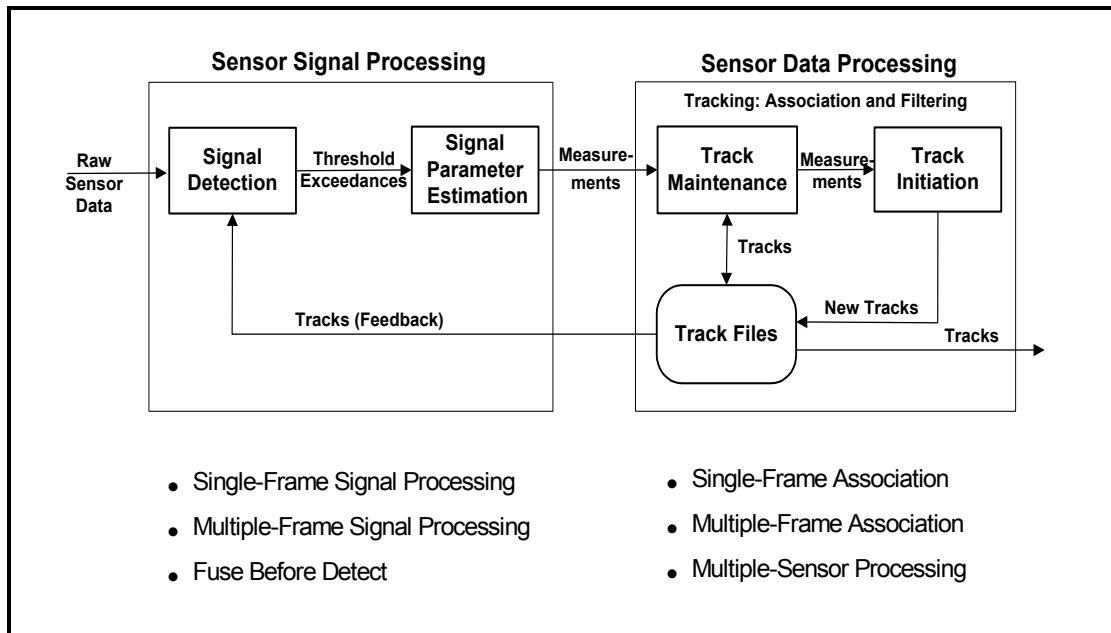


Figure 1. Sensor Signal and Data Processing

This conference has provided a forum to address these issues through discussion of algorithms and simulations for both digital signal processing and target tracking, i.e., association (correlation) and filtering, including related data processing, such as sensor fusion, sensor resource management, and target classification. Of the six half-day sessions, one addressed signal-level processing and six 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 papers contain a wealth of information that address the issues critical to practical processing under the challenging conditions outlined above. For example, important advances are presented in: novel signal processing methods, a variety of multiple frame data association methods, track filter methods to accommodate non-linearities, advanced distributed sensor data fusion, improved methods for tracking maneuvering targets, feature-aided tracking, processing with unresolved close-spaced objects, processing registration biases, management of multiple sensor resources, fusion open issues, tracking ground targets, 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. This year we had a workshop on Tuesday evening with an open discussion on future prospects for algorithm development of track and related data processing plus a demonstration of a new large-scale network-centric tracking testbed. This workshop, which is entitled Demonstration and Open Discussion, has become a regular annual event, as have the daily Small Target Luncheon Dialogues.

We thank the authors, session chairs, attendees, and SPIE coordinators for making the three-day conference, the luncheon dialogues, and the evening workshop such successes. 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 at the luncheons 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
Email: Drummond@Att.Net