PROCEEDINGS OF SPIE

Signal and Data Processing of Small Targets 2013

Oliver E. Drummond
Richard D. Teichgraeber
Editors

28–29 August 2013
San Diego, California, United States

Sponsored and Published by
SPIE

Volume 8857

Proceedings of SPIE 0277-786X, V. 8857

Signal and Data Processing of Small Targets 2013, edited by Oliver E. Drummond,
Richard D. Teichgraeber, Proc. of SPIE Vol. 8857, 885701 · © 2013 SPIE
CCC code: 0277-786X/13/$18 · doi: 10.1117/12.2046046

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Author(s), "Title of Paper," in *Signal and Data Processing of Small Targets 2013*, edited by Oliver E. Drummond, Richard D. Teichgraeber, Proceedings of SPIE Vol. 8857 (SPIE, Bellingham, WA, 2013) Article CID Number.

ISSN: 0277-786X
ISBN: 9780819497079

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

Printed in the United States of America.

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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.

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Introduction

This was the 25th 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 2-D target large enough for ATR is typically larger than 100 resolution elements, for example, larger than 10 by 10 pixels. In contrast, this conference series introduced a different thrust for SPIE in 1989: processing targets smaller than 100 pixels.

This year the conference was held in San Diego after being held in Baltimore the prior year. In the future, these conferences are expected to be located in Baltimore in the spring on *even* years and continue to be in San Diego in the summer on *odd* years. The proceedings of the prior conferences in this series in 1989 through 2012 are SPIE Volumes 1096, 1305, 1481, 1698, 1954, 2235, 2561, 2759, 3163, 3373, 3809, 4048, 4473, 4728, 5204, 5428, 5913, 6236, 6699, 6969, 7445, 7698, 8137, and 8393. 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 threat clouds, such as Chem/Bio threats.

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 with data from a single sensor has been studied extensively, there are still many interesting challenges in this field. In contrast, the state of the art of sensor data fusion and for processing small extended-objects, clusters, and Chem/Bio clouds is far less mature, but interest is growing. The topic of Chem/Bio has been added because the methods for tracking clusters of objects and tracking of small extended-objects may be applicable with modification. Similarly, the topic of processing for defense against cyber threats has been added because the processing methods developed for target tracking may be helpful.

Small targets that are not point source objects include dismounts, 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 and Chem/Bio processing offers significant advantages and unique challenges since they can change in size, shape, and orientation as well as motion.

New or improved sensors, increasingly demanding system requirements, efficacious countermeasures, severe operating environments, processor hardware limitations, new innovative processing methods, 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 along with the limitation in sensor resolution.

Note that the process of algorithm development is emphasized here because Monte Carlo simulations are needed to obtain functional performance of tracking with confidence. Tracking functional performance is not amenable to mathematical analysis because it depends on random variables from both continuous sample space and discrete sample space. This property makes algorithm design, performance evaluation, and the entire algorithm development process complex and challenging. No surprise that performance results can initially appear counter intuitive.

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, MHT methods use in cyber domain, target classification/typing, processing of features and attributes, efficient signal processing and tracking of Bio/Chem clouds, adaptive tracking, and the interaction between signal processing and tracking. Many of these issues are highlighted in Figure 1. In addition, there is a need for an indication of track quality and related information 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 finalizing 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.

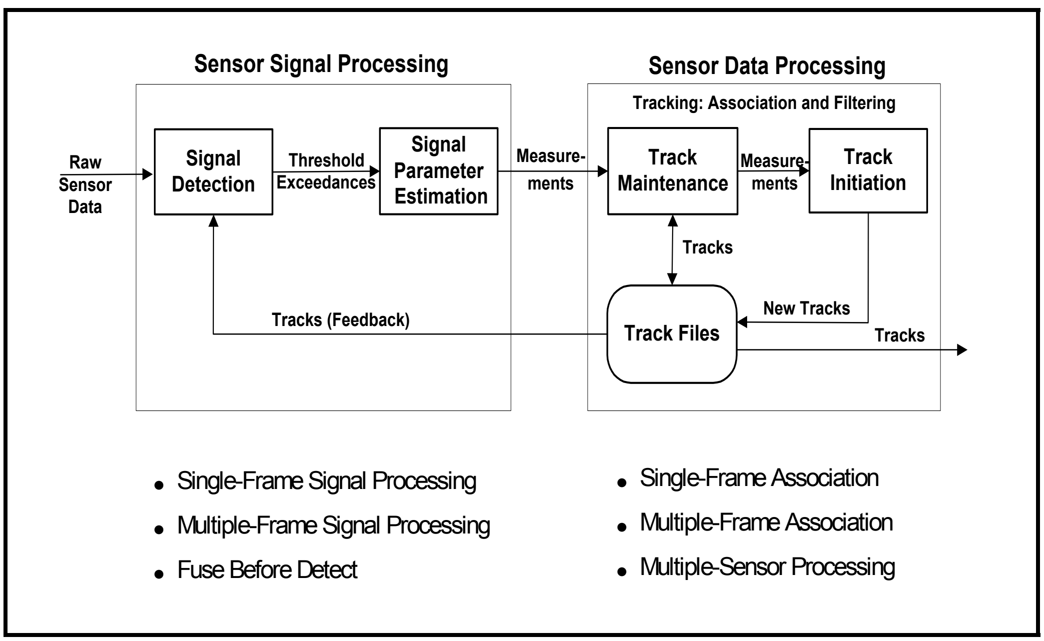

Figure 1. Sensor Signal and Data Processing

This conference series has provided a forum to address these issues through discussion of algorithms and simulations for digital signal processing, target tracking, and sensor data fusion, i.e., the functions of data association (correlation) and filtering, including related data processing, such as system resource management, and target classification/typing, all under challenging conditions. Of the three half-day sessions this year, one addressed signal-level processing, one addressed target tracking and related functions, and one addressed signal and data processing including 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 were presented in: filter methods to accommodate non-linearities, alternative data association approaches, improved distributed sensor data fusion, processing data of dismounts, high fidelity signal simulation methods, multiple sensor resource management, and cyber network intrusion detection. These techniques and others presented are strong candidates to contribute to achieving high performance target tracking and sensor data fusion plus 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 coordinators for making this 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 the poster session 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.

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Workshop Topic:
Signal and Data Processing

Presentation Title:
Conference Overview

This Series of Conferences Has Added A Daytime Workshop.

The conference proceedings and the SPIE Digital Library will use a copy of each author's PowerPoint file instead of a manuscript. See slides 8 and 9 of the presentation that follows for more details about these Workshops

SPIE Conference Overview

Signal and Data Processing
Of Small Targets 2013

28 August 2013

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Abstract

This conference overview addresses the types of targets and the major characteristics of the data encountered in processing sensor data for tracking targets.

The presentation summarizes why tracking these targets make the processing of this data so complex and challenging. The discussion includes a view of the algorithm state of the art, the current drivers in algorithm development, and the critical open issues.

Future direction of this series of conferences is discussed and audience suggestions are invited.

Sp13ConfOvrVw4.Ppt 2

Types of Target Tracking

- **Sensor Tracking A Single Target**
  Typically "Closed Loop Tracking" Drives Target Detection To Center Of Field Of View
- **Tracking Large Targets**
  Image Processing Or Image Understanding Permit Identification Of Components Of Target
- **Tracking Medium Sized Targets**
  Correlation Or Ellipsoid Tracker Takes Extent Into Account
- **Tracking Small Targets**
  Isolated and Multiple Target Tracking Methods Handle Ambiguities Caused By Closely-Spaced Detections

Target *Size* Refers To Number Of Resolution Elements (Pixels) In Target Extent

Sp13ConfOvrVw4.Ppt 3

Conference Topics

- **Types Of Target**
  - Point Source Targets — Typically Less Than 20 Pixels Total
  - Small Extended Objects — Less Than About 70 Pixels Total
  - Clusters Composed Of Point Source And/Or Small Extended Objects
  - Detection and Tracking of Lethal Chem/Bio Clouds
- **Type Of Processing**
  - Sensor Signal Processing
  - Sensor Data Processing
    - Tracking: Association And Filtering
    - Target Typing/Classifying
    - Sensor Data Fusion Including Sensor Tasking, Global Resource Management, and Situation Assessment
- **Other Processing Tasks That Could Benefit From Algorithms Developed For Multiple Target Tracking**

Sp13ConfOvrVw4.Ppt 4

Algorithm Development Drivers

- New or Improved Sensors
- Demanding System Requirements
- Processor Hardware Limitations
- Severe Operating Conditions
- Challenging Threat Scenarios
- New Innovative Processing Methods

Sp13ConfOvrVw4.Ppt 5

Signal and Data Processing

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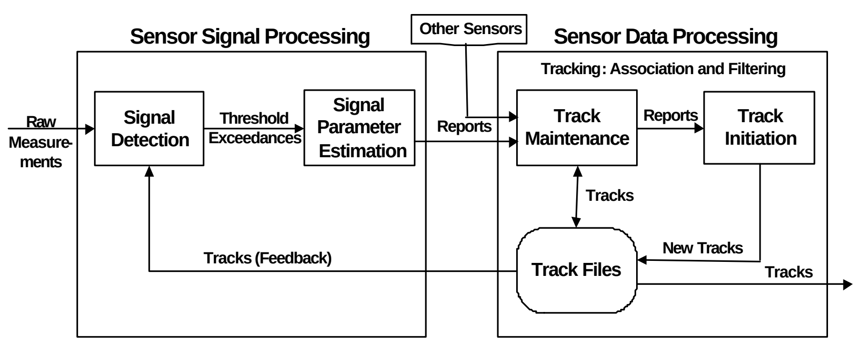

- Single Frame Signal Processing
- Multiple Frame Signal Processing
- Fuse Before Detect

- Single Frame Association
- Multiple Frame Association
- Multiple Sensor Processing

A Candidate Sensor Signal & Data Processing Chain

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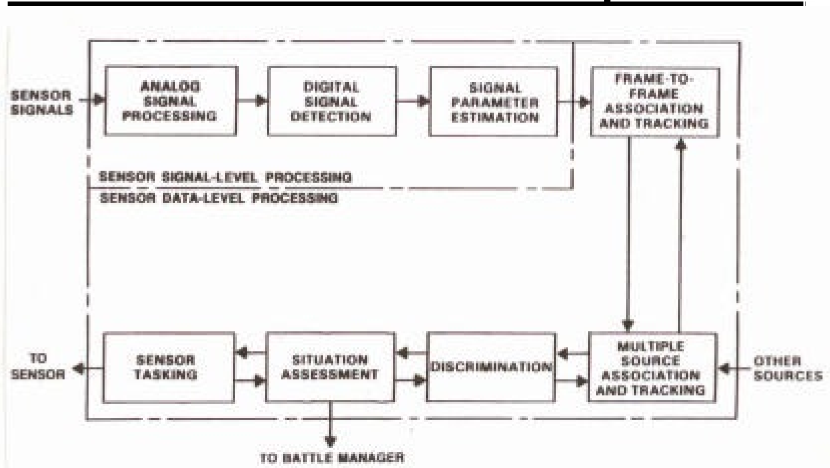

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This Series of Conferences Has Added A Daytime Workshop

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- **This Workshop Is Similar to a Typical Session of This Conference Except:**
  - The conference proceedings and the SPIE Digital Library will use a copy of each author's PowerPoint file instead of a manuscript.
  - The Workshop authors retain their copyright.
- **Workshop is Intended for an Author:**
  - Whose project has produced significant partial results that should be presented but urgency of the project makes preparing a manuscript now impractical *and/or*
  - Who can easily modify an existing PowerPoint file for the conference and
  - Who will present orally as scheduled or ensure that a colleague will.
- **All Workshop PowerPoint Files Will be Included in the Front Matter of the Proceedings and Thus in the SPIE Digital Library With Free Access**

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More on the Workshop Presentations

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- **Submission of Abstracts to Call-for-Papers**
  - Topics appropriate for Workshop identical to conference regular session.
  - For Abstract {only} add "{WORKSHOP}" to beginning of presentation "Title".
  - For Author Preferred Presentation Type indicate "Oral Presentation."
  - Workshop is limited to at most 8 presentation chosen by organizers
- **Conference Proceedings and SPIE Digital Library Information**
  - PowerPoint (or similar) files will be collected and included in the Front Matter of the conference proceedings and hence included in the SPIE Digital Library with Free Access.
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  - First or second slide of the PowerPoint file is to include a copy of the text of the Abstract.
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Some Critical Issues

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- **Low Observables and Limited Sensor Resolution**
- **Dense Environment - Targets, Clutter, False Signals**
- **Target Maneuvers and Non-linearities**
- **Counter Measures**
- **Sensor Data Fusion - Biases, Model Errors, Diverse Sensors**
- **Accurate Evaluations And Prediction Of:**
  - Functional Performance
  - Required Resources
- **Efficient Algorithms That Accommodate:**
  - Data Association and Filtering
  - Multiple Maneuver Models
  - Unresolved Closely Spaced Objects
  - Multiple Disparate Sensors and Advanced Fusion Functions
  - Adaptive Tracking and Failure/Damage Identification and Mitigation

Sp13ConfOvrVw4.Ppt 10

Multiple Target Tracking Algorithm Status

- **Limitations Of Existing Concepts And Algorithms**
  - Requires New or Excessive Resources Or
  - Unacceptable Tracking Functional Performance Or
  - Concepts Identified (Some Radically New) But Not Fully Developed and Performance Not Adequately Evaluated
- **Limited Progress Due To:**
  - Very Complex Problems such as Data Association
  - Few Commercial Applications
  - Classical Covariance Error Analysis Not Applicable - Monte Carlo Simulations Needed
  - Uncertainty of Which Target a Track Is Following Must Be Addressed
  - Complex Simulation Beyond Scope Of Normal Academic Research
  - Limited Algorithm Design, Development And Evaluation Funding
  - Shortage Of Detailed Documentation On Algorithm Development

Sp13ConfOvrVw4.Ppt 11

On The State-of-the-Art Of Tracking
(A Personal Opinion)

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- **The State-of-the-Art of Tracking With Data From a Single Sensor Under Challenging Conditions Has Improved Greatly in Recent Years Relative to What Is Achievable, but With Some Exceptions.**
- **Current Multiple Target Processing Methods Do *Not* Handle the Following Conditions Very Well:**
  - Advanced sensor data fusion and attribute/feature processing
  - Unresolved closely spaced objects or multipath.
  - Target splits; track splits and merges.
  - Extended objects, especially those that cause multiple detections.
  - Dense targets and clutter but small frames, i.e., with few measurements in each frame (possibly overlapping).
  - Frames with multiple measurements for the same target.
  - Accommodating mathematical model errors and errors in estimates of sensor/target characteristics, possibly non-stationary.

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Some Observations On Target Tracking (1 of 2)

MTT Lecture Notes

- **Tracking Small Targets Involves Random Variables from Both Discrete and Continuous Sample Space, e.g., Measurement Errors and Assignment Errors:**
  - Because of the resulting complex nature of the estimation errors, multiple target-tracking performance evaluation and prediction are not amenable to analysis.
  - A high fidelity Monte Carlo simulation plus field testing are a necessary part of most tracking algorithm development efforts.
  - Some simulation results appear initially to be counterintuitive.
  - Algorithm development of the trackers for a system is typically an experimental and recursive process and a long lead task.
  - Tracking exhibits properties significantly different from signal processing; in addition to Type 1 and Type 2 errors, tracking exhibits Type 3 errors, that are a combination of both missed and false tracks.
  - Different Design Criteria Lead to Different Optimal Solutions.

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Some Observations On Target Tracking (2 of 2)

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- **By Comparison, for Linear Gaussian Filtering Problems (Without Need of Association Processing) the Kalman Filter Is Optimal For a Wide Variety of Optimization Criteria**
- **Because Optimal Tracking Performance Methods Are Too Complex to Be Practical, Constrained Optimal or Suboptimal (Ad Hoc) Algorithms Are Typically Devised That Take Advantage of the Particular Targets, Sensors, and Related Conditions of the System for Which the Tracker Is Designed.**
  - In algorithm development, the major trade is between tracking performance versus cost, processor loading, and communications loading, if applicable.
  - Note that the {Kalman} filter equations are not very difficult to implement; it is the selection of the type of filter, structure of the mathematical model, and its parameter values used to design the filter that require extensive knowledge and experience. The data association function is similar.

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Considerations For Next Year

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- **We Are Open to Your Suggestions**
- **Permit Workshop Presentations**
- **How Handles Presentations That Withhold Some Information?**
- **Encourage Demonstrations - Video and PC ?**
- **Reinstitute Luncheon Dialogues ?**
- **Broaden Conference Scope ?**
- **Ideas for Evening Session ?**
- **Continue to Alternate Conference Locations:**
  - West coast on odd years
  - East coast on even years

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Conclusions

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- **Algorithm development for multiple small target tracking is typically:**
  - Challenging
  - Complex and seldom amenable to mathematical analysis
  - Poses extensive algorithm development,
  - Is a long lead task,
  - Must be customized for each application,
  - Consequently, off-the-shelf solutions are NOT practical
- **Small target signal and data processing methods have improved significantly in recent years relative to what is achievable, but there are still opportunities for major progress.**
- **Your suggestions for future conferences are invited and can be anonymous.**

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