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Oliver E. Drummond
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Introduction

This was the 26th 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 2D 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 Baltimore after being held in San Diego 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 volumes of the prior conferences in this series in 1989 through 2013 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, 8393, and 8857. A CD 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 tracking multiple, close- targets 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 chem/bio clouds, adaptive tracking/data fusion, 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.

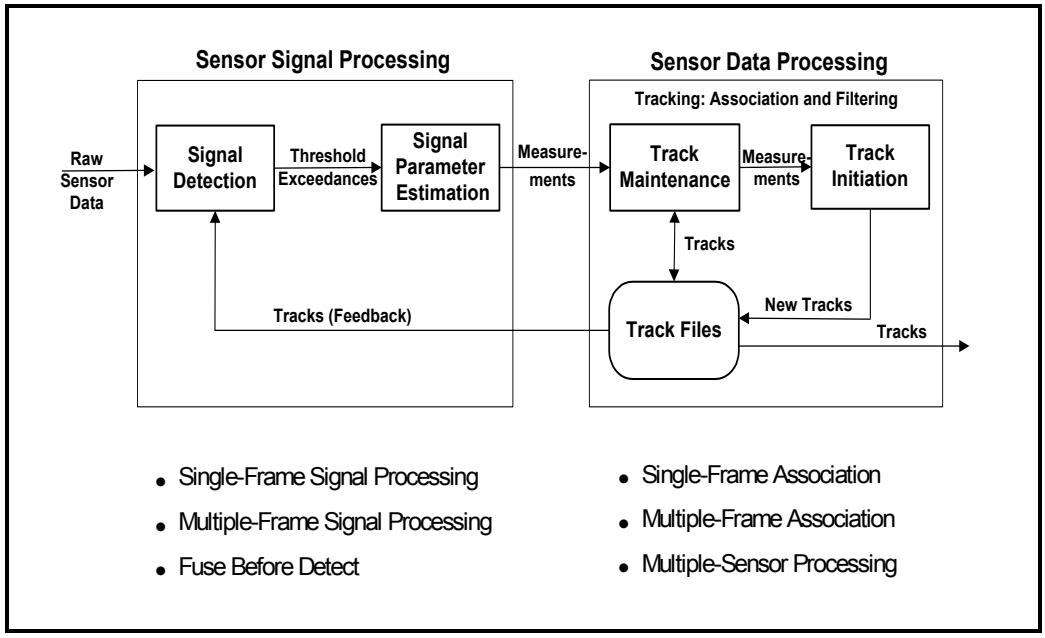

Figure 1. Sensor Signal and Data Processing

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 four half-day sessions this year, one addressed signal-level

processing, two addressed tracking small targets, 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: efficient particle filter methods to accommodate non-linearities, alternative data association approaches, improved sensor data fusion by estimation of sensor biases, use of attributes to improve target detection, and new metrics for evaluating uncertainty consistency and association ambiguity. The techniques 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 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:

Some fundamentals unique to tracking multiple, close, small targets

This series of conferences has added a daytime workshop. The conference proceedings and the SPIE Digital Library use a copy of each author's PowerPoint file instead of a manuscript.

Some Fundamentals Unique To Tracking Multiple, Close Small-Targets

8 May 2014

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Abstract

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Tracking multiple, close, small, targets using sensor measurements can exhibit fundamental characteristics that are unique compared to most other typical estimation processing.

A common cause is the misassociations due to close measurements relative to the sensor accuracy. The possibility of misassociations greatly complicates the development process and causes it to be uniquely challenging and both the performance evaluation process and the track processing to be complex. For simplicity, the discussion of random variables from continuous sample space is limited to those that are generated by linear, Gaussian process.

The discussion includes typical causes of the complexity, some strictly optimal design criteria, some practical constraints to reduce process complexity, and the complications of performance evaluation.

Ground Rules

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- **Lots to address, so limit scope (unless indicated otherwise) to comparing two trackers, for which:**
  - Both trackers observe four targets and target measurement errors are independent
  - Simple tracker gates receive only one measurement in each track gate
  - Challenging tracker gates average more than one measurement in each gate
  - The pertinent *apriori* probabilities are known
  - Limit discussion to multiple, small targets and continuous measurement error sample space

The Methodology

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- **The Assumed Methodology**
  - Define the desired system characteristics
  - Enumerate the processing equations and parameters
  - Select the performance criteria
  - Find the optimal solution
  - Evaluate performance and hardware resources required
- **Some performance criteria include:**
  - Minimum Mean Square Error (MMSE)
  - Maximum Aposteriori Probability (MAP)
  - Best Hypothesis (BH)

Some Differences in Results From MMSE Trackers

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- **Simple Tracker Implemented Four Single-Target, Recursive Trackers**
- **Challenging Tracker Implemented One Integrated Process with Tracks for Four Target that includes Smoothing (Retrodiction).**
- **Classical Covariance Error Analysis is Applicable to Simple Tracker but is NOT Applicable to Challenging Tracking -- so a Monte Carlo Simulation is Needed**
- **Note: Complex Simulation Development is Beyond the Scope Of Normal Academic Research**
- **For Simple Tracker, Most Bayesian Cost Criteria lead to the same Solution, NOT so for the challenging Tracker**

Some Observations On Target Tracking (1 of 2)

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- **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 mathematical analysis.
  - A high fidelity Monte Carlo simulation plus field testing are a necessary part of most tracking algorithm development efforts.
  - Initially, some simulation results appear 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.

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.

Conclusions

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- **Algorithm development for multiple, close small-target tracking is typically:**
  - Definitely Challenging
  - Complex and seldom amenable to mathematical performance analysis
  - Poses extensive algorithm development,
  - Is a long lead task,
  - Must be customized for each application,
  - Consequently, off-the-shelf solutions are NOT practical
  - Is at least as Challenging as Rocket Science
- **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.**