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13. ABSTRACT (Maximum 200 words) This grant is supporting the development an approach to sensor management based on information theoretic metrics. These methods can be used to optimize data collection with agile multimode sensors such as phased array radar systems, electro-optical imaging systems and passive radio frequency systems to improve detection, tracking and classification. For FY96 an information theoretic metric was extended to a more general type of probability density referred to as joint multitarget densities for use when the targets are dynamic and their number is unknown. In this application there is correlation between target-number uncertainty target-location uncertainty which must be accounted for in the statistics model and in the sensor management metric. Joint multitarget conditional probabilities are used to solve this problem. Target dynamics are modeled as Markov processes. The expected discrimination gain for sampling any cell is computed and the sensor is directed at the maximizing cell for each sample. In comparison to direct sampling, optimizing the discrimination increases the probability of detecting and localizing the targets. These results are summarized in an invited conference paper. An expanded version of this paper is now in preparation for submission to a refereed journal.

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FY 1996 Progress Report for AFOSR

Sensor Management

Grant Number: AFOSR/F49620-95-1-0307

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Grant Objectives: Develop mathematical foundations for sensor management with an emphasis on metrics.

Status of Effort: This grant is supporting the development an approach to sensor management based on information theoretic metrics. These methods can be used to select dwell points and modes for collections of agile multimode sensors such as phased array radar systems, electro-optical imaging systems and passive radio frequency systems to improve detection, tracking and classification performance. For FY96 two issues were examined. First, the basic information theoretic metric was extended to a more general type of probability density referred to as joint multitarget densities. Second, a performance comparison of information theoretic metrics compared to several alternatives was performed for detection problems.

Accomplishments/ New Findings: Treating the problem of simultaneous detection, tracking and classification in multitarget, multisensor applications is a challenging issue for sensor management. One of the significant new findings generated by this grant for FY96 has been the development of a method to treat problems where the number of targets is unknown and the targets can move. This leads to an approach to sensor management based on a) tracking the probability for an unknown number of targets using a collection of joint multitarget probabilities and b) maximizing the expected discrimination gain for each sensor dwell. This was applied to the problem of detecting and tracking a collection of dynamic targets in a surveillance volume consisting of a collection of discrete cells where the number of targets is not known a priori. A major problem in this type of application is that there is correlation between the uncertainty in the number of targets and the uncertainty in their locations. This must be accounted for in both the statistical model used to describe the target set and in the metric used to determine how to direct the sensor for each dwell. The statistics model developed to solve this problem uses a joint multitarget conditional probability $p(c_1, \dots, c_n | Z)$ for the probability that a) there are exactly n targets and b) that they are located in cells c_1, \dots, c_n , based on a set of observations Z . Given a sensor model, $p(c_1, \dots, c_n | Z)$ is updated for each n and c_i after each measurement using Bayes' rule. Target dynamics are modeled as a Markov process which leads to a time-evolution of $p(c_1, \dots, c_n | Z)$, independent of the measurements. The expected discrimination gain for sampling any cell can be computed. The sensor is directed at the maximizing cell for each sample. In comparison to directly sampling all of the cells, optimizing the discrimination significantly increases the probability of detecting and localizing all of the targets. These results are summarized in an invited conference paper. An expanded version of this paper is now in preparation for submission to a refereed journal.

Another area of investigation supported by this grant was a performance comparison of alternative sensor management schemes. Several schemes based on information theoretic metrics such as discrimination gain have been proposed, motivated by their generality

ability to accommodate mixed types of information such as kinematic and classification data. On the other hand, there are many methods for managing a single sensor to optimize detection. In collaboration with Stan Musick at Wright Laboratory, the performance against low signal-noise ratio targets of a discrimination gain scheme was compared with three such single sensor detection schemes: a sequential probability ratio test (the 'Wald test'), an index policy that has been shown by David Castanon to be optimal under certain circumstances and an 'alert-confirm' scheme modeled on methods used in some existing radars. For the situation where the index policy is optimal, it outperforms discrimination gain by a slight margin. However, the index policy assumes that there is only one target present. It performs poorly when there are multiple targets while discrimination gain and the Wald test continue to perform well.

One issue that arises with the use of discrimination gain as a metric is that it depends on both the current density and an a priori distribution. Under the support of this grant, we examined the dependence of discrimination gain on this prior and demonstrated that while the discrimination depends on the prior, the gain is prior-independent. This is a useful observation because it eliminates a significant source of uncertainty in defining the sensor manager.

An objectives of this grant is to foster university/industry interaction. As part of this, Lockheed-Martin Tactical Defense Systems (LMTDS) sponsored Mr. Troy Jenison as an intern during the summer of 1995. Under the direction of Dr. Keith Kastella, he implemented a version of the detection and classification algorithm using improved data structures. The earlier version of the algorithm was quite slow, which only made it practical to study problems with about 100 detection cells. With the heap-based algorithm, problems with 100,000 and 1,000,000 cells are accessible on a PC. With this, we have examined how a measure of the error probability varies as a function of the average number of sensor samples per cell and the total number of cells. The surprising result that has come to light is that when discrimination based search is used, this error probability is independent of the number of cells for a fixed number of average sensor samples per cell. Similar results are obtained for classification with multiple target types and multiple sensors, as well as simple detection. In contrast to this behavior, for direct search the error rate rises rapidly if the average number of samples per cell is held fixed and the number of cells increases.

In addition, we explicitly showed how discrimination gain can be extended to static multisensor / multitarget detection and classification problems that are difficult for these other methods. Discrimination gain was applied to a problem with one detection sensor and one classification sensor. Initially, the detection sensor is used exclusively. It is only after the existence of a target has been established that any benefit can be derived from classification sensor. This is correctly represented by the discrimination gain based approach. This is a desirable behavior for the algorithm since it means that dwells with the classification sensor are not wasted on empty cells.

Personnel Supported: This grant directly supports a subcontract to Lockheed-Martin Tactical Defense Systems (LMTDS) for research support to Dr. Keith Kastella, an LMTDS employee. Also, LMTDS is sponsoring Dr. Michael Kouritzin, an Institute for Mathematics and Its Applications (IMA) postdoctoral fellow. He is working with Dr. Kastella in the area of nonlinear filtering, a problem area related to sensor management. LMTDS has also sponsored Mr. Troy Jenison in an internship (summer, 1995) working full-time with Dr. Kastella on sensor management. Mr. Jenison will receive his Master of Science in Mathematics from the Minnesota Center for Industrial Mathematics at the University of Minnesota. Mr. Jenison's sensor management work at LMTDS forms the basis for his Master's thesis.

Publications: This grant supported *Discrimination Gain to Optimize Detection and Classification*, Keith Kastella, will appear in the Jan. 1997 IEEE Transactions on Systems, Man and Cybernetics. *Event Averaged Maximum Likelihood Estimation and Mean-field Theory in Multi-Target Tracking*, Keith Kastella, IEEE Transactions on Automatic Control, pp. 1070-1073, Vol. 50, No. 6, June 1995 was partially supported by this grant. The related work *Tracking Algorithms for Air Traffic Control Applications*, Keith Kastella and Mark Biscuso, Air Traffic Control Quarterly, Vol 3(1) pp. 19-43, (1995). was developed under a separately funded effort.

Interactions/Transitions:

Meetings: Three papers presented at the Society of Photo-Optical Instrumentation Engineers (SPIE) International Symposium on Optical Science, Engineering, and Instrumentation, 9-14 July, 1995, San Diego, CA:

A preliminary version of *Discrimination Gain to Optimize Detection and Classification*; *Comparison of mean-field and joint probabilistic data association trackers in high-clutter environments*, Keith Kastella and Charles Lutes;
Asymptotic Estimate for Missed/False Track Probability in Track-Before-Detect Algorithms, Mark Copeland and Keith Kastella.

Comparison of Sensor Management Strategies for Detection and Classification, Stan Musick and Keith Kastella, 9th National Symposium on Sensor Fusion, 11-13 March 1996, Naval Postgraduate School, Monterey, CA

The Search for Optimal Sensor Management, Keith Kastella and Stan Musick, SPIE International Symposium on Aerospace/Defense Sensing and Controls, 8-12 April, 1996, Orlando, FL.

A Nonlinear Filter for Altitude Tracking, Keith Kastella and Michael Kouritzin, First International Conference on Nonlinear Problems in Aviation and Aerospace, Embry-Riddle Aeronautical University, Daytona Beach Fl, 9-11 May, 1996.

Discrimination Gain for Sensor Management in Multitarget Detection and Tracking, Keith Kastella, IMACS Multiconference on Computational Engineering in Systems Applications in Lille, France, July 9-12, 1996.

New discoveries, inventions or patent disclosures: The application of joint multitarget probabilities and discrimination gain optimization to manage sensors for dynamic detection, tracking and classification of dynamic targets is new invention.

Patent #5,451,960, "Method of Optimizing the Allocation of Sensors to Targets", Keith Kastella, Wayne Schmaedeke was awarded September 19, 1995.

Honors/Awards: Dr. Kastella gave invited papers at the *First International Conference on Nonlinear Problems in Aviation and Aerospace*, Embry-Riddle Aeronautical University and *IEEE-SMC/IMACS Multiconference on Computational Engineering in Systems Applications* in Lille, France, July 9-12, 1996.