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ABSTRACT

This project's focus is on sensor management and associated issues in modeling, estimation, image reconstruction, and classification, for radar sensing. The central thesis of our original proposal was that intelligent sensor management can provide gains in performance and in operational requirements (energy consumption, deployment time, or exposure to hostile fire). We believe that we have demonstrated this thesis for several key application areas of interest to the army. These areas include minesweeping and
detection of UXO, radar multiple target tracking, and energy-aware radar imaging through walls, earth or other attenuating media.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

"Single-stage waveform selection for adaptive resource constrained state estimation," R. Raghuram, R. Raich and A.O. Hero, IEEE Intl. Conf. on Acoustics, Speech, and Signal
Processing, Toulouse France, June 2006, <http://www.eecs.umich.edu/%7Ehero/Preprints/army06_final.pdf>

"Adaptive Multi-modality Sensor Scheduling for Detection and Tracking of Smart Targets," C. Kreucher, D. Blatt, A. Hero, and K. Kastella,/ Digital Signal Processing/, Digital Signal Processing, vol. 16, no. 5, pp. 546-567, Sept. 2006. (.pdf) <http://www.eecs.umich.edu/%7Ehero/Preprints/2005DSP.pdf>. ScienceDirect link (.html) -

"Convergent incremental optimization transfer algorithms: application to tomography", S.
"Convergent incremental optimization transfer algorithms: application to tomography", S.
Ahn, J.A. Fessler, D. Blatt, and A. Hero, IEEE Trans. on Medical Imaging, vol. 25, no. 3,
pp.283-296, March 2006.

"Sensor Management Using An Active Sensing Approach" C. Kreucher, K. Kastella, and A. Hero, Signal Processing, Vol. 85, No. 3, pp. 607-624, March 2005.

"Multitarget Tracking using a Particle Filter Representation of the Joint Multitarget Probability Density," C. Kreucher, K. Kastella, and A. Hero, IEEE Transactions on Aerospace and Electronic Systems, vol. 41, No. 5, July 2005.

"An Enhanced Microwave and Millimeter-wave Foliage Propagation Model, Wang, F., and K. Sarabandi, " IEEE Transactions on Antennas and Propagation, Vol. 53, no. 7, pp. 2138-2154, July 2005.

 "A New Approximate Solution for Scattering by Thin Dielectric Disks of Arbitrary Size and Shape," Koh, I., and K. Sarabandi, IEEE Transactions on Antennas and Propagation, vol. 53, no. 6, pp. 1920-1926, June 2005.

"Adaptive Multi-modality Sensor Scheduling for Detection and Tracking of Smart Targets",
C. Kreucher, D. Blatt, A. Hero, and K. Kastella, Digital Signal Processing,vol. 15, no. 4,
July 2005.

"Multitarget Tracking using the Joint Multitarget Probability Density," C. Kreucher, K.
Kastella, and A. Hero, IEEE Transactions on Aerospace and Electronic Systems,
39(4):1396-1414, October 2005 (GD Medal winner 2005).

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"Secure space-time communication," A. O. Hero , IEEE Trans. on Info Theor,, Vol. 49, No. 12, pp. 1-16, Dec. 2003.

"Unicast-based inference of network link delay distributions using mixed finite mixture models," M.F. Shih and A. O. Hero, IEEE Trans. on Signal Processing, vol. 51, No. 9, pp. 2219-2228, Aug. 2003.

Number of Papers published in peer-reviewed journals: 12.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

"Iterative Redeployment of Illumination and Sensing (IRIS): Application to STW-SAR Imaging," J. A. Marble, R. Raich and A.O. Hero, Proc. of 25th Army Science Conference, Nov. 2006, <http://www.eecs.umich.edu/%7Ehero/Preprints/de18-patwari.pdf>

"Optimal sensor scheduling via classification reduction of policy search (CROPS)," D. Blatt and A.O. Hero, 2006 Workshop on POMDP's, Classification and Regression (Intl Conf on Automated Planning and Scheduling (ICAPS)), Cumbria UK, June 2006. (Invited)

"APOCS: a convergent source localization algorithm for sensor networks," D. Blatt and A.O. Hero, IEEE Workshop on Statistical Signal Processing (SSP), Bordeaux, July 2006.

"Incremental optimization transfer algorithms: application to transmission tomography", S. Ahn, J.A. Fessler, D. Blatt, and A. Hero, IEEE Conf on Medical Imaging, Oct. 2005.

"A Comparison of Task Driven and Information Driven Sensor Management for Target Tracking," C. Kreucher, A. Hero, and K. Kastella, 44th IEEE Conference on Decision and Control (CDC) Special Session on Information Theoretic Methods for Target Tracking, December 12-15, 2005. (Invited)

"Parallelized Physics-based Foliage Wave Propagation Model", Pierce L., and K. Sarabandi, Proceeding: The 2003 EMCC Annual Meeting, Virginia, May 20-22, 2003.

"Modeling of Millimeter-wave Signal Propagation Through Dense Foliage", Wang, F., I. Koh, and K. Sarabandi, Proceeding: 2003 CTA Annual Symposium, April 29 – May 1, 2003. (Invited)

"Detection and Identification of Landmines Utilizing Acoustic and Electromagnetic Waves," Sarabandi, K., and D.E. Lawrence, 6th Annual Army Landmine Basic Research, DoD Joint UXO office, January 23, 2003.

"Multitarget sensor management using alpha divergence measures," C. Kreucher, K. Castella, and A. O. Hero, Proc First IEEE Conference on Information Processing in Sensor Networks (IPSN) , Palo Alto, April 2003.

 "A Bayesian Method for Integrated Multitarget Tracking and Sensor Management", C..Kreucher, K. Kastella, and A. Hero, 6th International Conference on Information Fusion, Cairns, Australia, July 2003

"Particle filtering and information prediction for sensor management", C. Kreucher, K. Kastella, and A. Hero, 2003 Defense Applications of Data Fusion Workshop, Adelaide, Australia, July 2003.

"Information Based Sensor Management for Multitarget Tracking", C. Kreucher, K. Kastella, and A. Hero, Proc. Workshop on Multiple Hypothesis Tracking: A Tribute to Samuel S. Blackman, San Diego, CA, May 30, 2003.

"Reduced dimensionality inverse scattering using basis functions," A.E. Yagle, Workshop on Inverse Scattering, Stanford University, August 2003.

"Sequential Adaptive Multi-Modality Target Detection and Classification using Physics-Based Models," A.E. Yagle, A.O. Hero (presenters), K. Sarabandi, M. Bownik, DARPA ISP, Orlando FL, October 2003.

"Sequential Adaptive Multi-Modality Target Detection and Classification using Physics-Based Models," A.E. Yagle (presenter), A.O. Hero, K. Sarabandi, M. Bownik, DARPA ISP Kickoff, 18 Sep 02, Annapolis MD

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Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):   0

Peer-Reviewed Conference Proceeding publications (other than abstracts):

"APOCS: a convergent source localization algorithm for sensor networks," D. Blatt and A.O. Hero, IEEE Workshop on Statistical Signal Processing (SSP), Bordeaux, July 2006

"Incremental optimization transfer algorithms: application to transmission tomography", S. Ahn, J.A. Fessler, D. Blatt, and A. Hero, IEEE Conf on Medical Imaging, Oct. 2005.

"A Comparison of Task Driven and Information Driven Sensor Management for Target Tracking," C. Kreucher, A. Hero, and K. Kastella, 44th IEEE Conference on Decision and Control (CDC) Special Session on Information Theoretic Methods for Target Tracking, December 12-15, 2006 (Invited)

"Optimal sensor scheduling via classification reduction of policy search (CROPS)," D. Blatt and A.O. Hero, 2006 Workshop on POMDP's, Classification and Regression (Intl Conf on Automated Planning and Scheduling (ICAPS)), Cumbria UK, June 2006. (Invited)

"Tests for global maximum of the likelihood function," D. Blatt and A. O. Hero, Proc. of IEEE ICASSP, Philadelphia, March, 2005.

"Non-myopic Approaches to Scheduling Agile Sensors for Multitarget Detection, Tracking, and Identification," (Invited) C. Kreucher, and A. Hero, Proc of IEEE ICASSP, Philadelphia, March 2005

"Particle Filtering for Multitarget Detection and Tracking," C. Kreucher, M. Morelande, A. Hero and K. Kastella, IEEE Aerosense Conference, March 2005

"Information-based Sensor Management for Simultaneous Multitarget Tracking and Identification," (Invited) C. Kreucher, A. Hero, K. Kastella, and B. Shapo, The Proceedings of The Thirteenth Annual Conference on Adaptive Sensor Array Processing (ASAP), June 7 - 8 2005.

"Multiplatform Information-based Sensor Management," C. Kreucher, K. Kastella, and A. Hero, The Proceedings of the SPIE International Symposium on Defense and Security, volume 5820, pages 141-151, March 28 - April 1, 2005

"Optimal experimental design for an inverse scattering problem," R. Rangangaran, R. Raich and A. O. Hero, Proc. of IEEE ICASSP, Philadelphia, March, 2005.

"Sequential Design of Experiments for a Rayleigh Inverse Scattering Problem," R. Rangarajan, R. Raich, and A.O. Hero, Proc. Of IEEE Workshop on Statistical Signal Processing (SSP), Bordeaux, July 2005.

"Macro-modeling foliage path-loss based on SWAP model simulations," Wang, F., and K. Sarabandi, Proceeding: IEEE International Geoscience and Remote Sensing Symposium, Seoul, Korea, July 24-29, 2005.

"FDTD and single scattering formulation for simulation of foliage camouflaged hard targets," Dehmollaian, M., H. Mosallaei, and K. Sarabandi, Proceeding: IEEE International Geoscience and Remote Sensing Symposium, Seoul, Korea, July 24-29, 2005.

"Polarization discrimination for improving foliage-camouflaged target detection," Dehmollaian, M., and K. Sarabandi, Proceeding: IEEE International Geoscience and Remote Sensing Symposium, Seoul, Korea, July 24-29, 2005.

"Electromagnetic Scattering from Foliage Camouflaged Hard Targets, in VHF-Band," Dehmollaian, M., H. Mosallaei, and K. Sarabandi, Proceeding: IEEE International Antennas and Propagation & URSI Symposium, Washington D.C., June 4-10, 2005.

"Macro-Modeling Foliage Path-Loss Based on a Statistical Wave Theory Model," Wang, F., and K. Sarabandi, Proceeding: IEEE International Antennas and Propagation & URSI Symposium, Washington D.C., June 4-10, 2005.

"Optimum Polarization for Foliage Camouflaged Target Discrimination Using a Genetic Algorithm," Dehmollaian, M., and K. Sarabandi, Proceeding: IEEE International Antennas and Propagation & URSI Symposium, Washington D.C., June 4-10, 2005.

"Analysis of Acoustic and Electromagnetic Wave Interaction Using Sheet Boundary Conditions and the Finite-Method," Buerkle, A. M., and K. Sarabandi, Proceeding: IEEE International Antennas and Propagation & URSI Symposium, Washington D.C., June 4-10, 2005.

"Accurate estimation of electromagnetic wave extinction through foliage," Wang, F., and K. Sarabandi, Proceeding: IEEE International Geoscience and Remote Sensing Symposium, Anchorage, Alaska, Sept. 20-24

"A New Scattering Formulation for Broad Leaves," Sarabandi, K., and I. Koh, Proceeding: IEEE International Geoscience and Remote Sensing Symposium, Anchorage, Alaska, Sept. 20-24, 2004.

"A Forward Scattering Model for Foliage Camouflaged Complex Target," Dehmollaian, M. and K. Sarabandi, Proceeding: IEEE International Geoscience and Remote Sensing Symposium, Anchorage, Alaska, Sept. 20-24, 2004

"Long-distance wave propagation through forested environments," Wang, F., and K. Sarabandi, Proceeding: National Radio Science Meeting (URSI), Boulder, Colorado, Jan. 5-8, 2004. (invited)

"Efficient methods of non-myopic sensor management for multitarget tracking," C. Kreucher, A. Hero, K. Kastella, and D. Chang, 43rd IEEE Conference on Decision and Control, December 2004.

"Phenomenology of Millimeter-wave Signal Propagation and Scattering for Detection of Targets Camouflaged Under Foliage", Sarabandi, K., and A. Nashashibi, Proceeding: IEEE International Geoscience and Remote Sensing Symposium, Toulouse, France, July 21-25, 2003.

"Wideband Radar Phenomenology of Forest Stands", Telpukhovskiy, E.D., V. P. Yakubov, K. Sarabandi, V. L. Mironov, and V. M. Tsepelev, Proceeding: IEEE International Geoscience and Remote Sensing Symposium, Toulouse, France, July 21-25, 2003.

"Theory and Measurements of Millimeter-wave Propagation Through Foliage", Wang, F., I. Koh, and K. Sarabandi, Proceeding: IEEE International Antennas and Propagation & URSI Symposium, Columbus, OH, June 22-27, 2003.

"Detection of Hard Targets Camouflaged Under Foliage Using Millimeter-wave Radars", Sarabandi, K., and A. Nashashibi, Proceeding: IEEE International Antennas and Propagation & URSI Symposium, Columbus, OH, June 22-27, 2003.

"On solutions to multivariate maximum alpha-entropy Problems", J. Costa, A. O. Hero and C. Vignat, in Energ Minimization Methods in Computer Vision and Pattern Recognition (EMM-CVPR), Eds. M. Figueiredo, R. Rangagaran, J. Zerubia, Springer-Verlag, 2003

"Asymptotic distribution of log-likelihood maximization based algorithms and applications," D. Blatt and A. Hero, in Energy Minimization Methods in Computer Vision and Pattern Recognition (EMM-CVPR), Eds. M. Figueiredo, R. Rangagaran, J. Zerubia, Springer-Verlag, 2003

"Tracking Multiple Targets Using a Particle Filter Representation of the Joint Multitarget Probability Density", C. Kreucher, C., Kastella, K., and Hero, A., SPIE, San Diego California, August 2003.

"Information-based sensor management for multitarget tracking", C. Kreucher, K. Kastella, and A. Hero, SPIE, San Diego, California, August 2003.

"Fast non-iterative 2D blind deconvolution of blurred images," A.E. Yagle and F. Al-Salem, SPIE, San Diego, California, August 2003.

"Blind superresolution from undersampled blurred measurements," A.E. Yagle, SPIE, San Diego, California, August 2003.

"Construction of signal-dependent Cohen's class time-frequency distributions using iterative blind deconvolution," A.E. Yagle, J.E. Torres-Fernandez, SPIE, San Diego, California, August 2003.

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts): 34

(d) Manuscripts

The PI is principal editor of an upcoming book on "Foundations and applications of sensor management," to be published by Springer in early 2007. This book was largely motivated by work developed in collaborations started under this MURI and includes contributors from academia, government labs (DoD), and industry. Several contributors have been supported by this MURI.

Number of Manuscripts: 1.00

Number of Inventions:

Graduate Students

NAME	PERCENT_SUPPORTED	
Jay Marble	0.38	
Neal Patwari	0.50	
Raghuram Rangarajan	0.05	
Krishnakanth Subramaniam	0.50	
Michael Fitzgibbons	0.50	
Sidharth Shah	0.50	
Doron Blatt	0.50	
Jose Costa	0.08	
Mojtaba Dehmollaian	0.50	
Feinian Wang	0.50	
FTE Equivalent:	**4.01**	
Total Number:	**10**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Mark Kliger	0.17
Cyril Alain Hory	0.25
Raviv Raich	0.25
Hossein Mosallaei	1.00
FTE Equivalent:	**1.67**
Total Number:	**4**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
M. Bownik	0.08	No
K. Sarabandi	0.08	No
A. Yagle	0.10	No
A.O. Hero	0.10	No
FTE Equivalent:	**0.36**	
Total Number:	**4**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Personnel receiving masters degrees

NAME
Sidharth Shah
Jay Marble
Krishnakanth Subramaniam
Mojtaba Dehmollaian
Total Number: 4

Names of personnel receiving PHDs

NAME	
Jose Costa	
Doron Blatt	
Neal Patwari	
Krishnakanth Subramaniam	
Sidharth Shah	
Total Number:	**5**

Names of other research staff

NAME	PERCENT SUPPORTED	
B. Lawson	0.15	No
FTE Equivalent:	**0.15**	
Total Number:	**1**	

Sub Contractors (DD882)

Inventions (DD882)

I Foreword

This is the final report for the ARO MURI Sequential Adaptive Multi-Modality Target Detection and Classification using Physics-Based Models, Grant number DAAD19-02-1-0262 over the period July 2002 through Sept. 2006

The MURI has supported four co-PI's, ten graduate students, and two post-doctoral fellows. Significant research progress has been made in this MURI. The MURI produced fifty publications, five PhDs, and four MSs in the areas of adaptive sensor management, image processing, and electromagnetic modeling. Several of the publications coming out of this MURI have won best paper awards. Technology transfer to General Dynamics, Raytheon, and to Army Night Vision Electronics Laboratory has occurred – several of the students supported on this MURI are now employees at these facilities and relevant software has been released to them. We offer these accomplishments as evidence of the success of this MURI. In this report we highlight these accomplishments.

II Statement of the problem studied

The focus of this MURI was to formulate implementable sequential detection, sensor management & selection strategies that could be applied to detection of mines, tracking stationary and moving targets under foliage and other attenuation and obscuration sources, and facilities detection and imaging. A key aspect of our project was to account for the physics of wave propagation and wave-target interaction to build tractable low dimensional models. Another key aspect was the derivation of bounds and approximations to optimal sensor scheduling performance, as specified by partially observable decision processes (POMDP) and greedy myopic sensor management algorithms.

III Summary of the most important results

The highlights of this MURI were development of strategies for the following area (student's associated with these projects are in parentheses):

1. Theory and application of information gain (IG) scheduling (Kreucher)
2. Classification reduction for reinforcement learning (RL) and POMDP (Blatt, Marble)
3. Optimal energy scheduling for detection and estimation of scatters (Rangarajan)
4. Approximation and modeling of EM scattering and propagation in inhomogeneous media (Koh&Wang).

1. Theory and application of information gain (IG) scheduling

It is well known that on-line scheduling of sensor actions can give major gains in performance relative to off-line scheduling. For example, in mine detection Larry Carin's group has shown a factor of greater than 2 improvement in number of correct detections for fixed false alarm rate.

Many researchers, including Carin, have used entropic measures such as information gain as a scheduling criterion. Information gain scheduling has advantages of simplicity and lack of dependence on the particular task – e.g., one can optimize the same criterion for detection, classification or tracking. Furthermore, simulations by us and others have shown low sensitivity to model mismatch and near optimality in terms of minimizing task-dependent risk. Such properties are important since, for example, one can be assured that if one schedules sensors for mine detection this schedule would also be near optimal for identification of mine type. However, until now there has not been any theory to back up the empirically observed insensitivity of information gain. Nor has there been a simple way to relate optimal scheduling to classification to facilitate design of optimal schedules. Finally, in the real multitarget tracking context no one has been able to implement scheduling for more than a few targets. We have made significant progress in these directions.

Introduction of Renyi information divergence gain: We introduced a new measure of information gain, called Renyi information divergence, and established that it has several advantages over other measures such as mutual information, entropy, or Fisher information (Kreucher&etal:IPSN03). Principal among these is a universality result that any risk function can be sandwiched between the Renyi alpha information gain for two different values of alpha (Kreucher&etal: CDC05). This implies that the information gain is a universal surrogate in a theoretically precise sense. We also showed that the Reny divergence is simply computed under the multi-target particle filtering model (Kreucher&etal: AES05) for the information state and that it is more robust to mismodeling errors than other information measures (Kreucher&etal: SP05). The details of modeling and implementation of Renyi information gain scheduling for multiple target tracking are discussed in (Kreucher: Thesis05).

Combined particle filtering and reinforcement learning for managed multi-target tracking: We leveraged on a mature methodology in the machine learning literature, known as relevance feedback learning, to schedule deployment of a suite of agile sensors (Kreucher&etal: SP05). Our method for managing agile sensors learns the number and states of a group of moving targets occupying a surveillance region. The system computes a sensing action to take based on the Renyi divergence. A measurement is made, providing relevance feedback and the system updates its probability density on the number and states of the targets. This procedure repeats at each time where a sensor is available for use. Due to the difficulty in computing the probability updates we have adopted a Bayesian Monte Carlo approach using particle. We have shown (using simulated measurements on real recorded target trajectories) that this method of sensor management yields a ten-fold gain in sensor efficiency when compared to standard unmanaged exhaustive scanning. This method has also been applied to the more difficult case where targets may stop and start or change dynamics in some other way using multiple model selection and hidden Markov state estimation (Kreucher&etal: ASAP04).

2. Classification reduction for reinforcement learning (RL) and POMDP

Reinforcement learning and POMDP approaches have been widely adopted for optimal scheduling and sensor management. One major difficulty in practical implementation of these

approaches is that the optimal scheduling policy is a complicated function of the distribution of the observations under each sensing action and under each hypothesis (for example mine or no mine). The common approach is to approximate the distribution and then use this approximation to estimate the average reward under various sensor actions by collecting a large amount of training data. The estimated optimal schedule, or policy, is obtained by maximizing the estimated rewards. A largely open problem is the question of generalization error: how many training samples does one need to guarantee that the estimated optimal policy will perform near optimally on the test samples? We made solid progress towards this objective by deriving bounds (Blatt: Thesis06) on the generalization error. These bounds can be used to predict the number of samples needed for a given model class, e.g. Gaussian distributed data. The method used to obtain these bounds is of interest in its own right since it converts the sensor scheduling problem into a sequential classification problem. As shown in (Blatt&Hero: NIPS05) this classification problem can then be solved using off-the-shelf classifiers such as radial basis functions, SVM, or kNN classifier structures. When applied to mine detection we obtain a performance curve that demonstrates the advantage of using non-myopic (2 stage) scheduling for deploying one of three confirmation sensors (GPR, EMI, or Seismic) for mine detection (Blatt&Hero:ICAPS06).

3. Optimal adaptive detection and estimation of scatters

Active radar waveform selection is an important problem that allows a sensing system to make optimal use of finite resources. For example, when the objective is imaging of a random medium with energy constraints, Papanicolau has shown that there is an optimal offline sequence of probing frequencies that depends on whether the objective is detection or image reconstruction. We have established results in different directions: optimal waveform selection in a predictive POMDP setting and optimal energy allocation for detection and image reconstruction.

Optimal energy scheduling: In (Rangarajan: SSP05) we resolved an open question: can one adaptively allocate energy over multiple dwells of a radar and achieve significant gains in estimation or detection performance for inferring the scatter medium? In particular, even when the radar is restricted to 2 dwells, we established that with for adaptive energy allocation can achieve almost 30% improvement of estimation accuracy relative to non-adaptive allocation. The fixed energy allocation concentrates all energy into single transmission during each signal period. The adaptive allocation takes advantage of the fact that if energy is divided over the signaling interval a small amount of energy may be sufficient to detect the presence of a strong scatterer, allowing one to keep energy in reserve for weaker and more ambiguous scatterers. Under a Rayleigh scattering model (Born approximation) the optimal strategy turns out to be to break up the energy into quanta and transmit a little energy initially, deciding to transmit more energy only if the first quanta generates a "good" observation (one with high instantaneous SNR). The characteristic "ramp" shape of the optimal energy allocation in time mimics the chirp type of waveform in frequency that is common in adaptive radar waveform design. A journal paper outlining our theory was recently accepted in the inaugural issue of the IEEE Journal on Selected Topics in Signal Processing (Special issue on waveform design) (Rangarajan&etal: JSTSP07).

Adaptive multichannel waveform selection and design. In (Rangarajan&etal: ICASSP06) we developed a significantly different approach to waveform selection than what has been previously proposed. The main challenge for multichannel adaptive waveform selection is the curse of dimensionality: as the number of channels increases the number of possible combinations of waveforms that can be transmitted through the set of channels increases exponentially. Thus exhaustive search methods for selection are not tractable. Furthermore, in an on-line sensor management setting decisions about the best waveforms to deploy at the next radar dwell can only depend on past measurments. We developed a method based on ensemble learning and generalized additive models (GAM) that breaks the exponential complexity logjam without appreciable loss in performance. This was demonstrated for radar tracking of a target with non-linear (two state) dynamics.

4. Approximation and modeling of EM scattering and propagation in inhomogeneous media

A hybrid full-wave and single scattering theory model was completed that can handle scattering of a hard target in a random medium. The model can compute scattering from the hard target in an exact manner, and accounts for first-order near-field interaction foliage and the hard target. A journal paper was just submitted on the topic. We have also completed a comprehensive foliage and hard target model, including near-field interactions for high frequencies. A journal paper was just submitted on the topic. We have also completed various foliage attenuation models. We have also completed a study on multi-polarization camouflaged target detection. A journal paper was just submitted.

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(Blatt: Thesis06) D. Blatt, *"Performance Evaluation and Optimization for Inference Systems: Model Uncertainty, Distributed Implementation, and Active Sensing,"* PhD Thesis, University of Michigan, May 2006.

(Kreucher&etal: IPSN03) C. Kruecher, K. Kastella, A. Hero, "Multi-target sensor management using alpha-divergence," Vol. 2634/2003, Information Processing in Sensor Networks: Second International Workshop, Lecture Notes in Computer Science, Springer, pp. 209-222, 2003.

(Kruecher&etal: ASAP04) C. Kreucher, A. Hero, and K. Kastella. "Multiple Model Particle Filtering for Multitarget Tracking," *The Proceedings of The Twelfth Annual Conference on Adaptive Sensor Array Processing (ASAP)*, March 16 - 18 2004.

(Kreucher&etal: SP05) C. Kreucher, K. Kastella, and A. Hero, Sensor Management Using An Active Sensing Approach. *Signal Processing*, 85(3): 607-624, March 2005.

(Kreucher&etal: AES05) C. Kreucher, K. Kastella, and A. Hero, "Multitarget Tracking using the Joint Multitarget Probability Density," *IEEE Transactions on Aerospace and Electronic Systems*, 39(4): 1396-1414, October 2005.

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