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An Integrated approach to the Space Situational Awareness Problem

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14. ABSTRACT
We have unified the finite Set Statistics (FISST) and Multi-Hypothesis Tracking (MHT) methodologies for multi-target tracking and developed a randomized version of FISST called RFISST that makes the implementation of the full FISST/ MHT recursions computationally tractable. The DDDAS paradigm used in this method actively controls the number of likely hypotheses, pruning them based on data coming from the sensors. We developed particle-based Gaussian Mixture Filters that are immune to the “curse of dimensionality”/ “particle depletion” problem inherent in particle filtering. This method maps the data assimilation/ filtering problem into an unsupervised learning problem. Results show that the performance is comparable to competing techniques. This is a thrust that is data driven to maintain the correct posterior density and uses the DDDAS paradigm. We developed a simulation based sensor scheduling scheme that can tackle the measurement steering problem inherent in all DDDAS applications. The algorithm is a heuristic solution to the underlying partially observed Markov Decision Problem (PMDP) that does not suffer from the “curse of Dimensionality and History" inherent in such problems, which allows recovery of true optimality.

15. SUBJECT TERMS
DDDAS paradigm; Gaussian Mixture Filters; particle depletion; Finite Set Statistics

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DDDAS AFOSR project FA9550-13-1-0074: An Integrated approach to the Space Situational Awareness Problem

The following papers were a result of this project.

Multi-Target Tracking

In this work, we have unified the finite Set Statistics (FISST) and Multi-Hypothesis Tracking (MHT) methodologies for multi-target tracking and developed a randomized version of FISST called RFISST that makes the implementation of the full FISST/ MHT recursions computationally tractable. The DDDAS paradigm is used in this method to actively control the number of likely hypothesis and for pruning them based on the data coming form the sensors.

W. Faber, S. Chakravorty and I. I. Hussein, " A Randomized Approach to the Solution of Multi-Target Tracking Problems", *FUSION 2015*

W. Faber, S. Chakravorty and I. I. Hussein, " A Comparison of RFISST and MHT for Space Situational Awareness Problems", , *Proceedings of the 2015 AAS/ AIAA Astrodynamics Specialists Conference*, Vail, CO.

W. Faber, S. Chakravorty and I. I. Hussein, " Multi-Target Tracking using a Randomized Hypothesis Generation Technique", *IEEE Transactions on Aerospace and Electronic Systems*, submitted

W. Faber, S. Chakravorty and I. I. Hussein, "An Improved Randomized Technique for Multi-Target Tracking", *FUSION 2016*

Particle Gaussian Mixture Filters

In this work, we have developed particle based Gaussian mixture filters that are immune to the "curse of dimensionality"/ "particle depletion" problem inherent in particle filtering and Gaussian Mixture Filters. As such, this method maps the data assimilation/ filtering problem into an unsupervised learning problem and results show that the performance is comparable, and frequently better, than competing techniques while it is able to scale to really high dimensional problems that the other techniques cannot due to the aforementioned problem of particle depletion. This is a thrust that is data driven to maintain the correct posterior density and thus, uses the DDDAS paradigm.

D. Raihan and S. Chakravorty, " A Hybrid Particle Filter-UKF algorithm for tracking Space Objects", *Proceedings of the 2015 AAS/ AIAA Astrodynamics Specialists Conference*, Vail, CO

D. Raihan and S. Chakravorty, "Particle Gaussian Mixture Filters I". *FUSION 2016*

D. Raihan and S. Chakravorty, "Particle Gaussian Mixture Filters II". *FUSION 2016*

Information Space Receding Horizon Control (I-RHC)

In this work, we have developed a simulation based sensor scheduling scheme that can tackle the measurement steering problem inherent in all DDDAS applications. The algorithm is a heuristic solution to the underlying partially observed Markov Decision Problem (PMDP) that does not suffer from the "curse of Dimensionality and History" inherent in such problems. Our ongoing work shows that this method is very well *motivated in the sense that with an intuitive tweak to the method, theoretically, it is able to recover true optimality. This thrust uses the DDAS paradigm in that it actively steers the measurement process, in this case the sensor schedule, such that the information regarding the targets is maximized.*

Z. Sunberg, S. Chakravorty and R. Erwin, "Information Space Receding Horizon Control for Multi-Sensor Tasking," *IEEE Transactions on Cybernetics, accepted,* to appear
M. Abusoltan, S. Chakravorty and S. Khatri, " A GPU based implementation of Sensor Scheduling for Space Situational Awareness", *FUSION 2016*

The following papers are not directly related to this project but are relevant to the DDDAS formalism, and have benefited from the synergy with this project.

Model Reduction
In this work, we have developed a model reduction technique that makes online model reduction for expensive black box models feasible. The method is a generalization of random projection and compressive sampling methods to the problems of model reduction for large scale systems. This method is orders of magnitude cheaper than competing techniques like Balanced Proper Orthogonal decomposition (BPOD) and also has orders of magnitude better accuracy at the same time. The DDDAS paradigm is used in that data is used to actively to perform online model reduction for very large scale systems such as chemical and pollutant transport problems.

D. Yu and S. Chakravorty, "A Computationally Optimal Randomized Proper Orthogonal Decomposition Approach", *Proceedings of the ACC 2016*
D. Yu and S. Chakravorty, "A Computationally Optimal Randomized Proper Orthogonal Decomposition Approach", *Automatica, submitted*

Distributed Data Fusion
In this work, we have unified the Consensus and Covariance Intersection (CI) based approaches to distributed Data Fusion that allows the hybrid technique to recover the performance of the Consensus based methods while being network agnostic and robust to unreliable networks like the CI approaches. The DDDAS paradigm enables us to use the data coming from multiple in a tractable but sub-optimal fashion such that we can form consistent estimates of the monitored field, this is important, for instance, in monitoring spatially varying fields such as chemical or pollutant transport.

A. Tamjidi, S. Chakravorty and D. Shell, "Unifying Consensus and Covariance Intersection for Decentralized State Estimation", *IROS 2016*

For legibility, we only attach the comprehensive versions of the papers on each of the above topics in the following.

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Abstract

In this work, we have unified the finite Set Statistics (FISST) and Multi-Hypothesis Tracking (MHT) methodologies for multi-target tracking and developed a randomized version of FISST called RFISST that makes the implementation of the full FISST/ MHT recursions computationally tractable. The DDDAS paradigm is used in this method to actively control the number of likely hypothesis and for pruning them based on the data coming form the sensors.
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A. Tamjidi, S. Chakravorty and D. Shell, "Unifying Consensus and Covariance Intersection for Decentralized State Estimation", IROS 2016

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