## NRI: FND: COLLAB: Distributed, Semantically-Aware Tracking and **Planning for Fleets of Robots**

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#### Goal

Enable safe and dependable operation of large-scale autonomous robotic fleets, such as autonomous vehicles and delivery drones, in complex and dynamic environments

#### **Key Problems**

- Classify and track stationary, dynamic, 2. and reactive objects in fast-paced dense
- Partition the environment and use this to distribute information across the



#### *urban environments*

- CNN-Based "Front End"
- Investigate Three Semantic, Multi-Target Estimation *"Back End"* Architectures



#### **Significant Contributions To Date**

- Introduced Semantic probability 1. hypothesis density (SPHD) filter
- Simultaneously detect, classify, and  $\bullet$ track large and time-varying object set



Comparison with MHT: PHD filter

team

- Visibility-Aware Partition
- Low-Bandwidth Communication
- *Robust Strategies* for Data Integrity
- Predict a range of possible future target 3. behaviors in order to plan safe actions
  - Planning For Reactive

Interaction

Learning for Reactive Prediction



- Introduced Distributed Rolling Window 3. 2. Tracker (DRWT)
  - Formulated distributed multi-target tracking as a maximum likelihood optimization
- Derived closed form local update rules for agents based on consensus ADMM
- Tested in high-fidelity driving simulator CARLA - CKF DRWT

- Enabled collaborative target search in mixed air-ground teams
- Create distributed representation that is provably identical to the centralized representation

Achieves higher accuracy in less time

J. Chen and Philip Dames. "Distributed Multi-Target Search and Tracking Using a

Coordinated Team of Ground and Aerial Robots." 2nd IEEE International Symposium

than homogeneous team

on Multi-Robot and Multi-Agent Systems (MRS). 2019.

**Broader Impacts** 

Account for heterogeneity in motion, sensing, and computation



### tracks fewer objects but with higher accuracy per object than MHT

J. Chen and P. Dames. "Multi-Class Target Tracking Using the Semantic PHD Filter." International Symposium on Robotics Research (ISRR). 2019.

J. Brodovsky. A Comparison of the Probability Hypothesis Density Filter and the Multiple Hypothesis Tracker for Tracking Targets of Multiple Types. 2019. Temple University, MS Thesis.

- Introduced Augmented Lagrangian 4. GAME-theoretic Solver (ALGAMES)
- Formulate trajectory planning for  $\bullet$ multiple interacting robotic agents as a Nash style game
- Developed a fast, online solver for  $\bullet$ game-theoretic trajectory optimization (ALGAMES) using augmented Lagrangian and quasi-Newton method
- Finds receding  $\bullet$ horizon freeway merging trajectories for three interacting cars at 60Hz



S. Le Cleac'h, M. Schwager, and Z. Manchester, "ALGAMES: A Fast Online Solver for Constrained Dynamic Games," Under Review.

Converges 100x faster than Consensus Kalman filter, to a target estimate with

#### 10% lower MSE

R. N. Haksar, O. Shorinwa, P. Washington, and M. Schwager. "Consensus-based ADMM for Task Assignment in Multi-Robot Teams", International Symposium on Robotics Research (ISRR). 2019.

- Introduced convex uncertainty Voronoi 5. (CUV) diagram
- Extends Voronoi diagram to account for position uncertainty
- Fully distributed algorithm
- Probabilistic guarantee on full coverage of environment by cell tessellation

Probabilistic guarantee on collision-free navigation

Chen and P. Dames. "Distributed and Collision-Free Coverage Control of a Team of Mobile Sensors Using the Convex Uncertainty Voronoi Diagram." American Control Conference (ACC). 2020. Accepted.



# CKF DRWT

#### Average total transmissions per node (kbit) Societal Impact

- Potential for greater mobility of people and goods
- Reduction in traffic congestion  $\bullet$
- Increased safety

#### **Education and Outreach**

- Student mentorship in lab at UG, MS, and PhD levels
- Senior design capstone projects
- Laboratory tours for K-12 students, visiting faculty, industry workers, etc.
- Inclusion in courses at Temple and Stanford



Voronoi Cell

**CUV Cell** 

Sensor

**UV Cell** 

#### 2020 NSF National Robotics Initiative Principal Investigators' Meeting

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