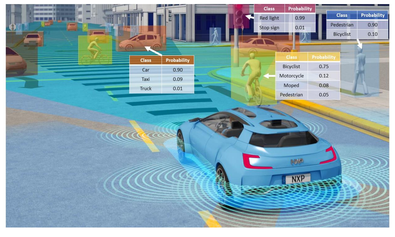
NRI: FND: COLLAB:
Distributed, Semantically-Aware Tracking and Planning for Fleets of Robots

Lead PI: Philip Dames (Temple University)
https://sites.temple.edu/trail

PI: Mac Schwager (Stanford University)
https://msl.stanford.edu/

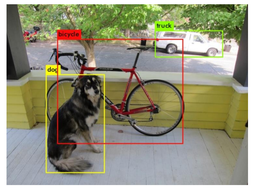
Goal

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

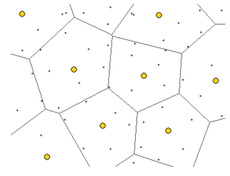


Key Problems

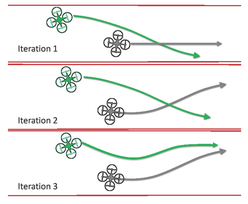
1. *Classify and track stationary, dynamic, and reactive objects in fast-paced dense urban environments*
   - *CNN-Based "Front End"*
   - *Investigate Three Semantic, Multi-Target Estimation "Back End" Architectures*



2. *Partition the environment and use this to distribute information across the team*
   - *Visibility-Aware Partition*
   - *Low-Bandwidth Communication*
   - *Robust Strategies for Data Integrity*



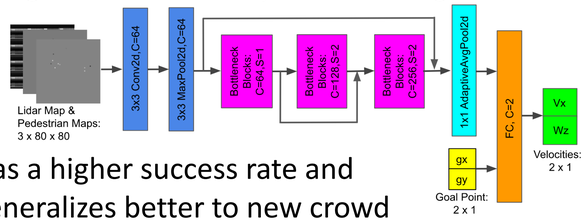
3. Predict a range of possible future target behaviors in order to plan safe actions
   - Planning For Reactive Interaction
   - Learning for Reactive Prediction



Significant Contributions To Date

Introduced CNN-based robot controller

- Uses early fusion architecture to combine lidar data with relative object kinematics to safely navigate in crowded dynamic settings



- Has a higher success rate and generalizes better to new crowd sizes and environments than either DWA or other CNN controllers

Z. Xie, P. Xin, and P. Dames, "Safe Navigation Through Crowded Dynamic Environments," In Proc. of IROS 2021. **Under review**.

Improved relative 6 DoF pose tracking using only onboard monocular camera

- Uses deep learning front-end to detect and track objects and UKF back-end to track 6 DoF pose
- Run 3 times faster than the fastest existing method, with 66% lower translational error and 23% lower rotational error

B. Ramtoula, A. Caccavale, G. Beltrame, and M. Schwager, "MSL-RAPTOR: A 6DoF Relative Pose Tracker for Onboard Robotics Perception," In Proc. of ISER 2021, **Accepted**.

Introduced Scalable Optimization Variable ADMM (SOVA)

- Exploit common separability property in multi-robot problems to reduce the state dimension
- Leads to 1.5-2.5 orders of magnitude faster convergence than Consensus ADMM (depending on graph topology)

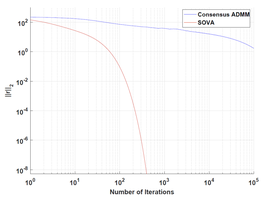
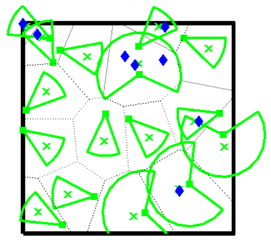


Fig. 7. Convergence rate of the consensus ADMM and Separable Optimization Variable ADMM (SOVA) methods on a maximum a posteriori (MAP) estimation problem with data distributed among 1000 agents. SOVA converges more than three orders of magnitudes faster than consensus ADMM.

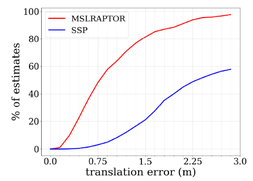
O. Shorinwa, T. Halsted, and M. Schwager, "Scalable Distributed Optimization with Separable Variables in Multi-Agent Networks." In Proc. of ACC 2020.

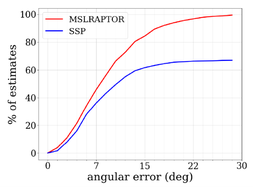
Introduced Normalized Unused Sensing Capacity (NUSC)

- Measures current usage rate of sensors in distributed sensing tasks
- Accounts for heterogeneity
- Use NUSC to equitably assign tasks using power diagram



J.Chen and P. Dames, "Distributed Multi-Target Tracking for Heterogeneous Mobile Sensing Networks with Limited Field of Views ," In Proc. of ICRA 2021, **Accepted**.

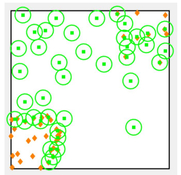




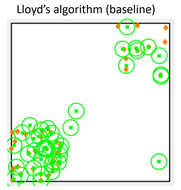
Formulate distributed search as multi-armed bandit (MAB) problem

- Create distributed Thompson sampling algorithm to solve MAB
- Propose distributed goal swapping algorithm to decrease total motion of team
- Improves exploration, especially when object distribution is uneven

J. Chen and P. Dames, "Active Multi-Target Search Using Distributed Thompson Sampling," In IEEE Robotics and Automation Letters 2021, **Under review**.



Lloyd's algorithm (baseline)



Thompson sampling (ours)

Broader Impacts

Societal Impact

- Potential for greater mobility of people and goods
- Reduction in traffic congestion
- Increased safety in human-filled environments

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

2021 NRI & FRR Principal Investigators' Meeting
March 10-12, 2021

Award ID#: IIS-1830419 (Temple)
IIS-1830402 (Stanford)