TEMPLE UNIVERSITY
College of Engineering

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

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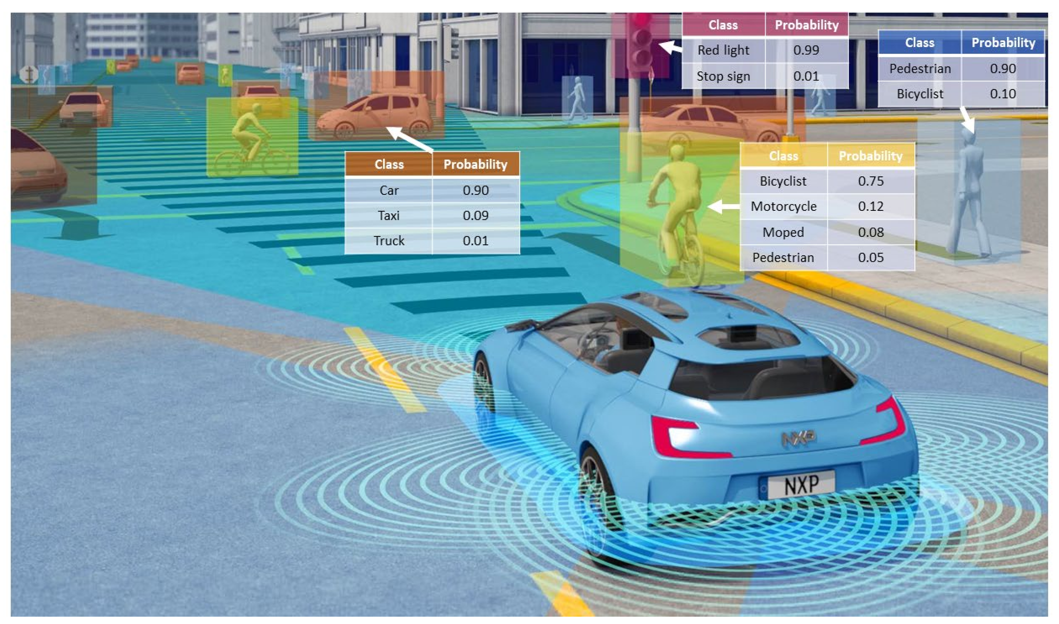
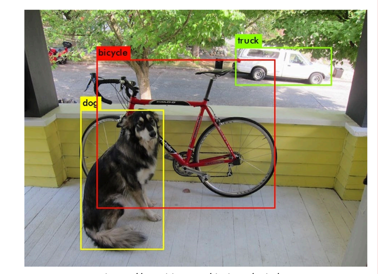
Abstract



- Goal: Enable safe and dependable operation of autonomous robotic systems
  - Thrust 1: Classify and track stationary, dynamic, and reactive objects in fast-paced dense urban environments
  - Thrust 2: Partition the environment and use this to distribute information across the team
  - Thrust 3: Predict a range of possible future target behaviors in order to plan safe actions
- Focus on two systems with potential for near-future deployment at large scale
  - Autonomous vehicles
  - Delivery drones

Thrust 1
Semantic Multi-Target Tracking

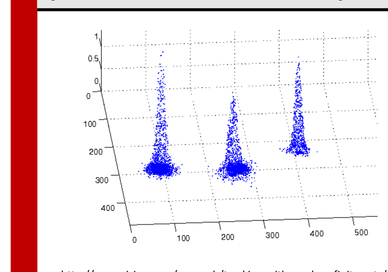
Task 1.1: CNN-Based "Front End"

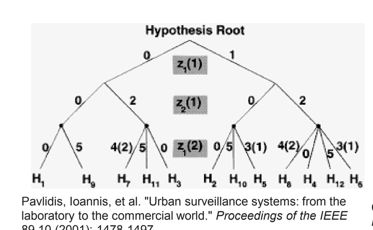


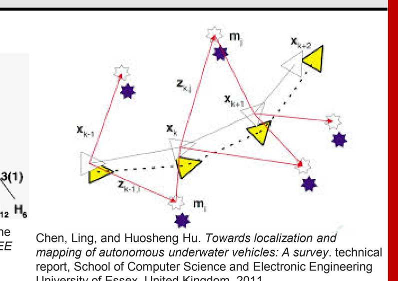
- Develop data-driven sensor models of:
  - Classification accuracy
  - Detection likelihood
  - False positive detection rate
  - Measurement noise
- Test on:
  - Data collected using our own systems
  - Open-source benchmarks e.g., KITTI and Stanford Drone Dataset

Task 1.2: Investigate Three Semantic, Multi-Target Estimation "Back End" Architectures

	PHD Filter	MHT	Pose Graph
Have target tracks?	No	Yes	Yes
Require data association?	No	No	Yes
Allow for robot pose uncertainty?	No	No	Yes

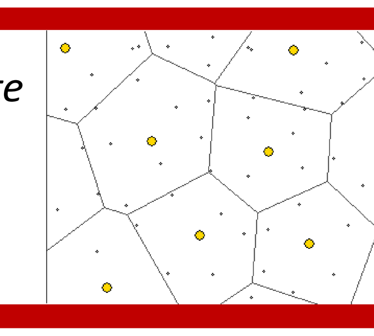






Thrust 2
Distributed Dynamic Environment Tessellation

Task 2.1: Visibility-Aware Partition

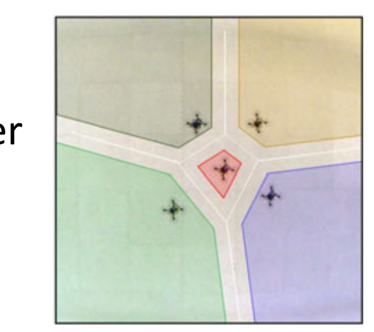


- Use partition to *spatially distribute* data storage
- Develop distributed versions of each tracking method

Task 2.2: Low-Bandwidth Communication

- Robot motion → update partition → data reassignment
- Develop approximate communication strategies
  - Fit any bandwidth budget
  - Provable bounds on loss of data

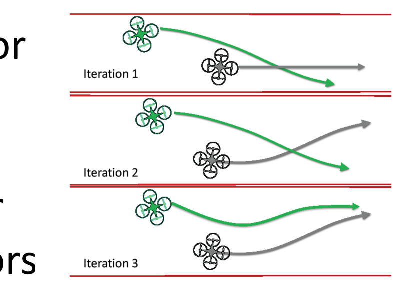
Task 2.3: Robust Strategies for Data Integrity



- Ensure data integrity in face of:
  - Systems errors: ex. network dropouts or failures
  - Malicious agents
- Buffered tessellation
  - Neighboring cells overlap, either partially or fully
  - Creates redundancy in the data storage across team
  - Use to discover rogue agents
  - Use to monitor self-health

Thrust 3
Semantically-Informed Online Planning

Task 3.1: Planning For Reactive Interaction

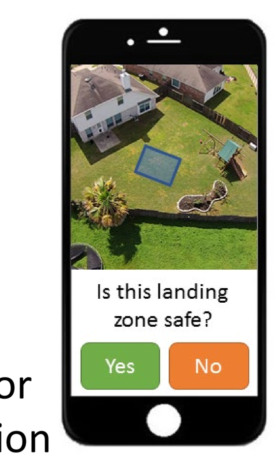


- *Reactive targets* change behavior based on proximity of robots
- Use receding-horizon, game-theoretic planner to account for range of possible target behaviors

Task 3.2: Learning for Reactive Prediction

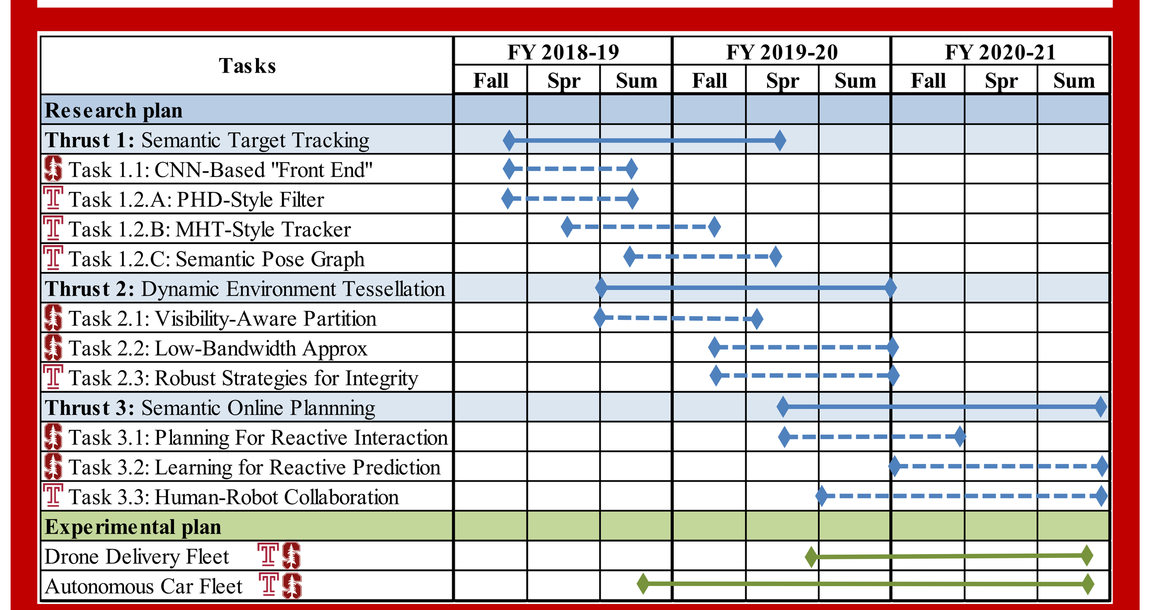
- Use data-driven policy learning
  - Associate one or more dynamic models with each semantic label
  - Update parameters of each model online using measurement innovation

Task 3.3: Software Tool for Human-Robot Collaboration



- If uncertainty is too great, enable robot to seek assistance from:
  - Nearby robot
  - Remote human
    - Develop phone app and/or web interface
      - Robot sends sensor data
      - Human can select target class or verify safety of a proposed action

Timeline

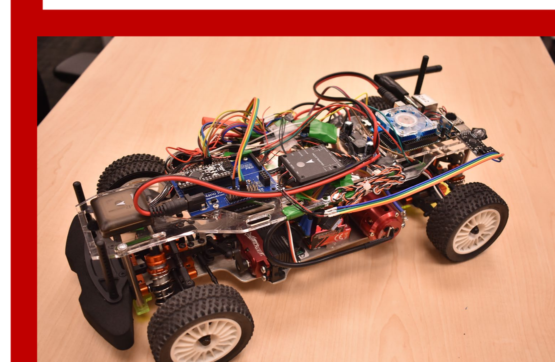


Facilities

- TRAIL (Temple Robotics and Artificial Intelligence Lab)
  - 1000 sq. ft. lab space
  - Qualisys motion capture system
  - Access to shared 2000 sq. ft. robotics and maker space (set to open in 2019-2020 academic year)
  - Access to Owl's Nest high performance computing cluster
- MSL (Multi-robot Systems Lab)
  - 1000 sq. ft. lab space
  - OptiTrack motion capture system
  - Access to shared 3000 sq. ft. UAV facility
  - Access to Stanford Research Computing Center (SRCC) computer clusters

Experimentation Plan

- Use identical hardware setups at Temple and Stanford
  - Enable verification across environments
  - Simplify code development
  - Increase portability of the code base



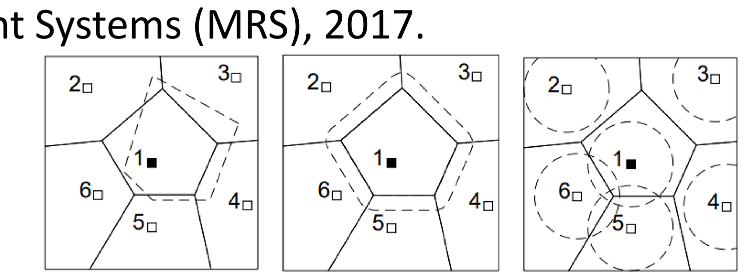
- 1/10 scale chassis
- PixFalcon autopilot
- Odroid XU4
- GPS, IMU

- DJI F330 frame
- PixFalcon autopilot
- Odroid XU4
- 3300 mAh LiPo battery

- Will release open-source:
  - Hardware bill of materials
  - Software (using ROS 2.0)
    - Uses DDS to enable distributed communication across team
    - Can handle network losses and delays
    - Can be deployed on wide variety of platforms, from embedded systems to high-power servers

Preliminary Results

- P. Dames. Distributed multi-target search and tracking using the PHD filter. In Proc. of the 1st IEEE International Symposium on Multi-Robot and Multi-Agent Systems (MRS), 2017.



(a) Particle exchange (b) PHD prediction (c) PHD update

- D. Zhou, Z. Wang, and M. Schwager. Fast, on-line collision avoidance for dynamic vehicles using buffered Voronoi cells. IEEE Robotics and Automation Letters, 2(2):1047–1054, 2017.
- M. Wang, Z. Wang, S. Paudel, and M. Schwager. Safe distributed lane change maneuvers for multiple autonomous vehicles using buffered input cells. In Proc. of the International Conference on Robotics and Automation (ICRA), 2018.
- R. Spica, D. Falanga, E. Cristofalo, E. Montijano, D. Scaramuzza, and M. Schwager, A Real-Time Game Theoretic Planner for Autonomous Two-Player Drone Racing, in Robotics: Science and Systems, 2018.
- A. Pierson, Z. Wang, and M. Schwager. Intercepting rogue robots: An algorithm for capturing multiple evaders with multiple pursuers. IEEE Robotics and Automation Letters, 2(2):530–537, 2017.

Broader Impacts

- Societal Benefits
  - Potential for greater mobility of people and goods
  - Reduction in traffic congestion
  - Increased safety
- Other use cases
  - Factory or warehouse robots
  - Household robots
- Education and outreach
  - Temple:
    - Undergraduate aerial robotics group
    - Senior design capstone projects
    - Inclusion in courses within the robotics sequence (currently in development)
  - Stanford:
    - Engage with existing REU program
    - Inclusion in existing undergraduate courses
      - Dawn of the Drones
    - Inclusion in existing graduate courses
      - State Estimation and Filtering for Aerospace Systems
      - Multi-Robot Control Communication and Sensing
  - Both:
    - Student mentorship within labs
    - Laboratory tours for K-12 students, visiting faculty, industry workers, etc.