NRI: FND: COLLAB: Distributed Bayesian Learning and Safe Control for Autonomous Wildfire Detection

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Motivation

- **Early detection** is a critical factor in mitigating wildfire damages to ecological systems and human infrastructure
- Aid wildfire prevention through continuous surveillance and early fire detection using autonomous aerial robots, equipped with visual, thermal, and chemical sensors and adaptive wireless comms
- **Scientific impact**: develop fundamental autonomy capabilities, including multi-modal environmental understanding, collaborative inference over robot networks, and multi-objective navigation with safety, communication, and energy constraints, that generalize to other areas of CPS research

Smog over Los Angeles (2002)

North California Wildfire (2018)

Task A: Online Metric-Semantic-Thermal Mapping

- Implicit surface representation via signed distance field (SDF)
- SDF approximation via Gaussian Process (GP) regression
- Mean and covariance of sparse support point set updated for each semantic class. Octree data structure maintains independent GPs with overlapping regions

Task B: Distributed Multi-robot Localization

- Distributed stochastic mirror descent (DSMD) algorithm allows agents to store and communicate probability density functions only over local variables (agent's own state and neighbors' states) and achieve efficient team localization

Task B: Persistent Monitoring

- Static path velocity controller to minimize an upper bound on the maximum Kalman filter eigenvalue at a set of interest points
- Two-level optimization for B-spline generation of dynamically feasible, uncertainty reducing UAV trajectories subject to control effort constraints

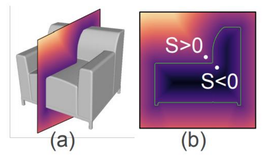
Task B: Adaptive RF Spectrum Utilization

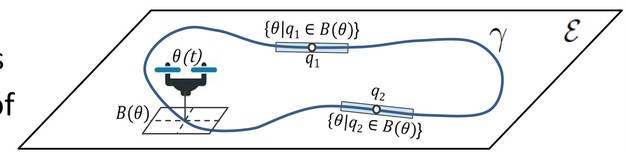
- UAV assignment and path optimization to maximize link quality (range, TX power, modulation, datarate) and spectrum usage in a collaborative robot team

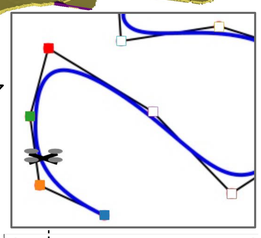
Distance to surface of S: $d(x, \partial S)$

Signed distance function:

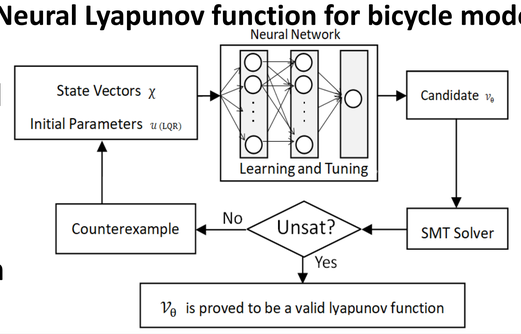
$$f(x) = \begin{cases} -d(x, \partial S), x \in S \\ d(x, \partial S), x \notin S \end{cases}$$

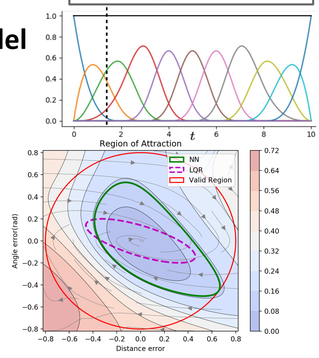






Neural Lyapunov function for bicycle model





Task C: Nonlinear System Control with Safety Constraints

- Given nonlinear system dynamics, learn a Lyapunov and associated controller jointly. Alternate between gradient-descent on the Lyapunov function parameters and SMT-driven search of counterexamples to the Lyapunov conditions
- **Significance**: first general framework for neural-network Lyapunov control design, significantly increasing the region of attraction for several important nonlinear control problems over LQR and SOS methods

Broader Impact (Education and Outreach)

- UCSD-SDSU collaboration to increase participation in robotics research
- **Activities**: develop small racecar robot with RGBD camera and python sim of 3-D environment; implement baseline algorithms for occupancy mapping, particle filter localization, path planning
- **Outreach**: presentations at SDSU Student Research Symposium (Feb 2020), UCSD Research Expo (April 2020); tutorials in Spring 2020

Broader Impact (Society)

- Supply critical real-time data to weather and fire spread simulators such as WIFIRE
- Provide early fire warning and improved situational awareness to first responders
- Impact on environmental monitoring, search and rescue, and transportation applications

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