Incorporating Human Input in Robotic Exploration

Millicent Schlafly, Katarina Popovic, and Todd Murphey

Collaborators: Katie Fitzsimons, Ahalya Prabhakar, Thomas Berrueta, Annalisa Taylor, and Chris Kim

Robots in the Wild: Challenges in Deploying Robust Autonomy for Robotic Exploration

Robotics: Science and Systems

Northwestern | McCORMICK SCHOOL OF ENGINEERING

Overview

- OFFSET Swarm Sprint
- June – November 2019
- Field testing

Motivation

Uncertain and dangerous environments (fires)

Active involvement of operator in scene (hurricane)

Many obstructions and time-critical (earthquake)

Ecological surveillance (Koh and Wich, 2012)

Current Methods of Control Allocation During Robotic Exploration

Fully Autonomous

Pro: enables advanced exploration techniques and multiple drones

Con: lack human intuition

Direct Control

Pro: adaptable to evolving task requirements

Con: requires large cognitive load

Current Methods of Control Allocation During Robotic Exploration

Fully Autonomous

Direct Control

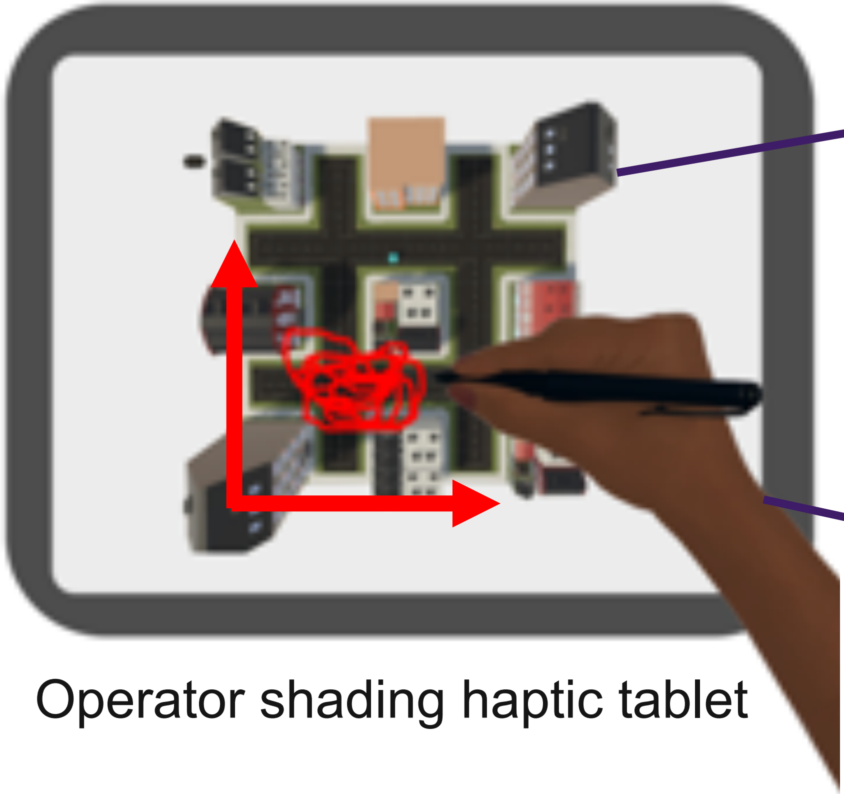
Shared Control

incorporating human knowledge of the task into control architecture

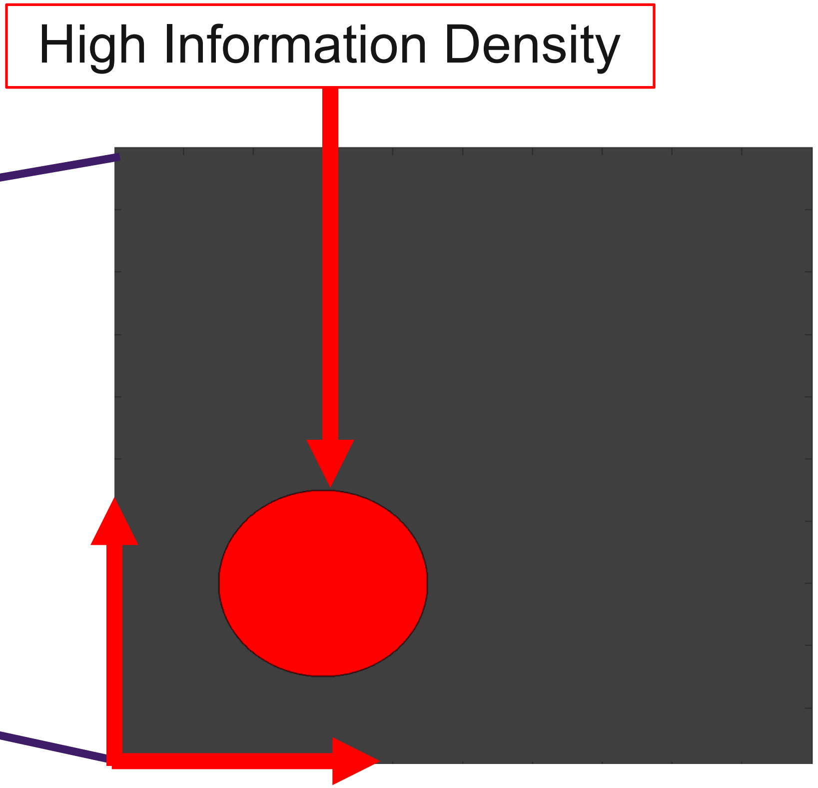
Our Approach:
Using Distributions to Incorporate an Operator Input

Incorporating User Input Into Spatial Distribution

Operator shades areas for robotic exploration



Operator shading haptic tablet



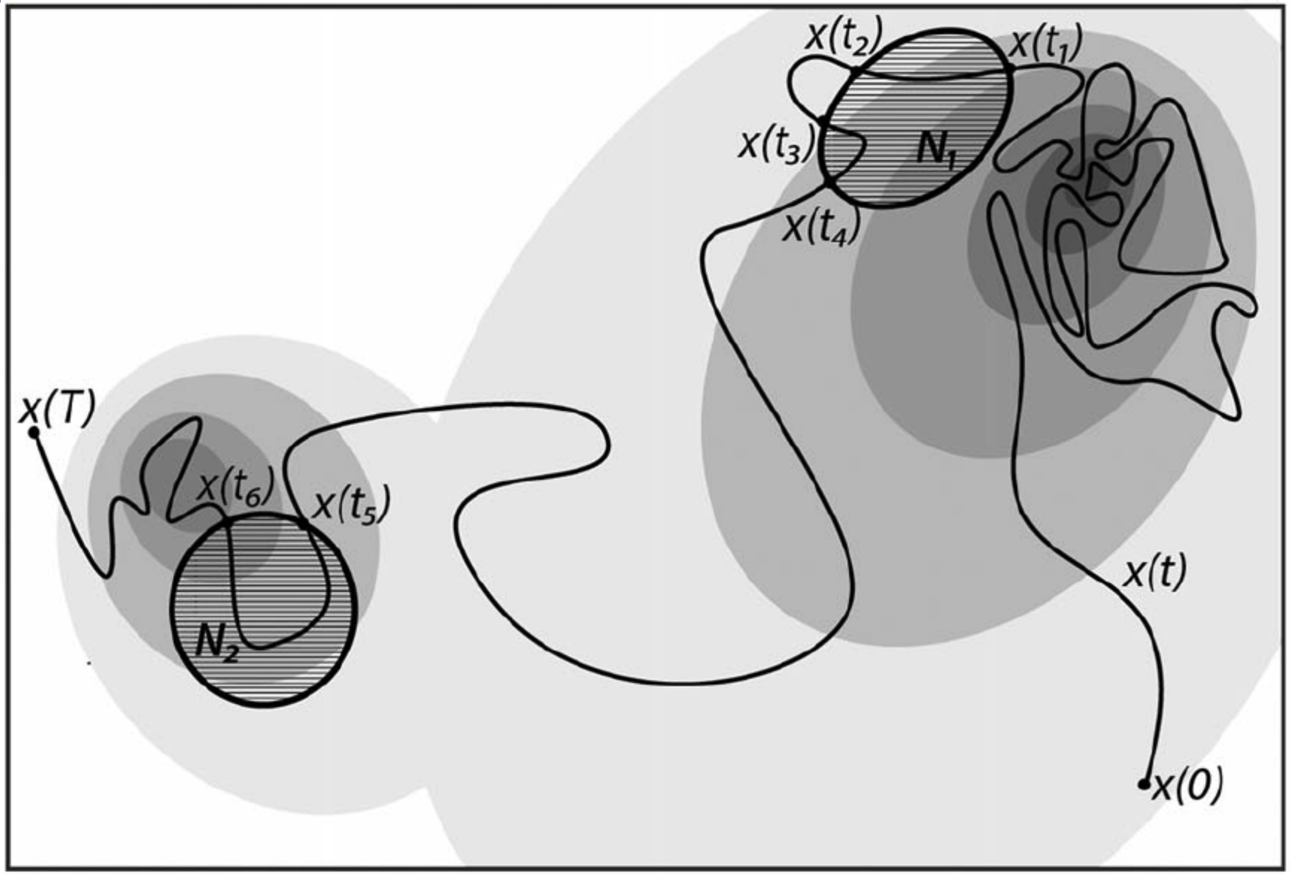
Spatial distribution of information density for control algorithm

Ergodic Control

- The time-averaged spatial distribution of the trajectory approaches the spatial distribution of expected information density

- Computed by minimizing the ergodic metric

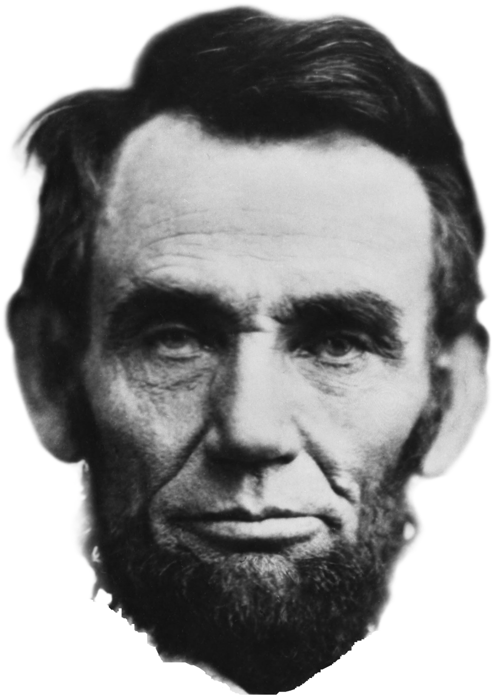
$$\varepsilon = \sum_{k_1=0}^{K} \dots \sum_{k_n=0}^{K} \Lambda_k |c_k - \phi_k|^2$$

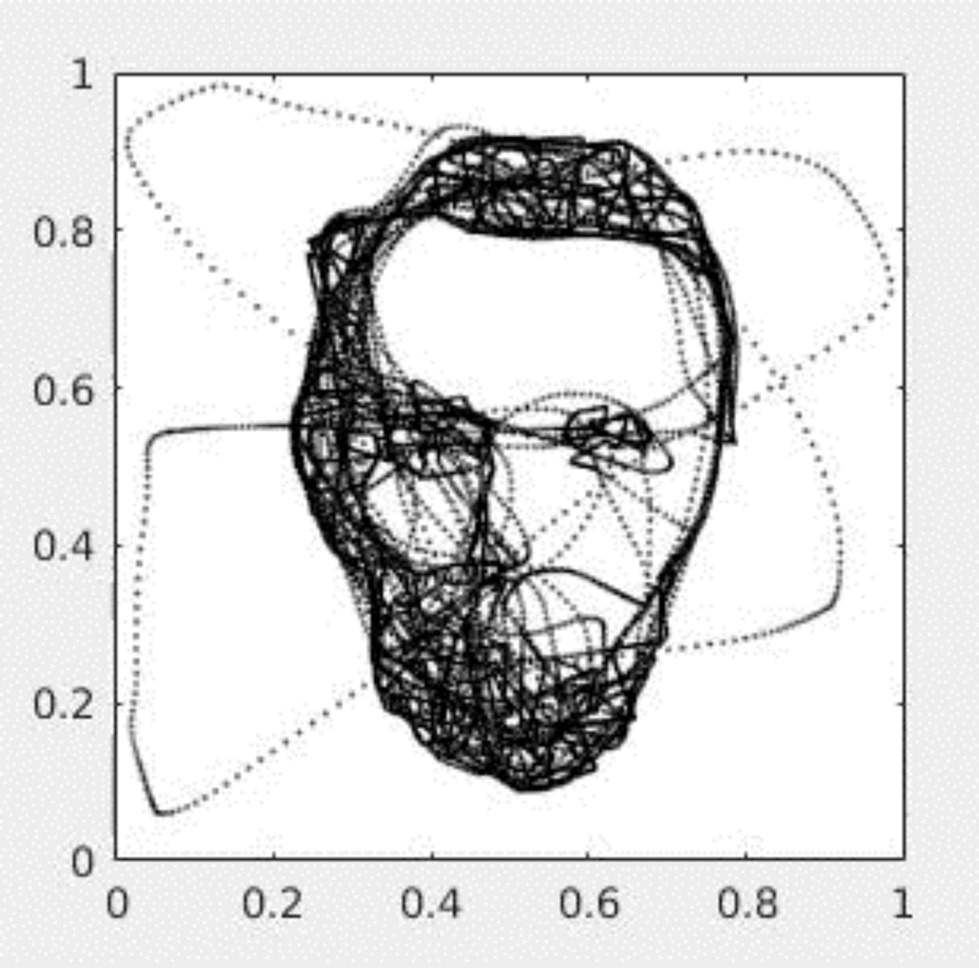


Example of ergodic trajectory [Miller, 2013]

Variability in Task Execution

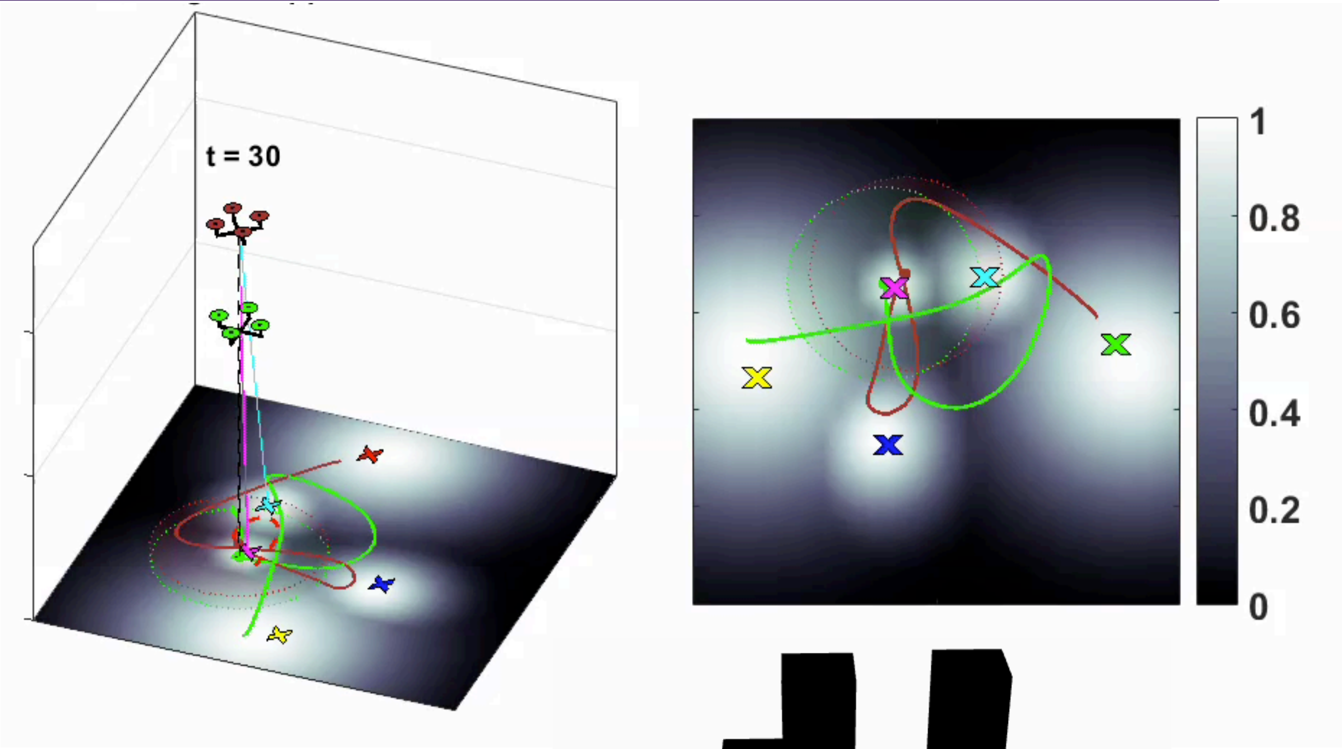
Robotic drawing task

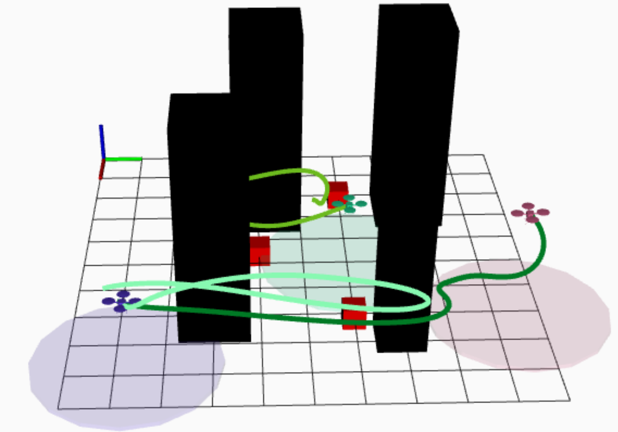




[*] Prabhakar A, Mavrommati A, Schultz J, and Murphey TD. "Autonomous visual rendering using physical motion." *WAFR* (2017).

Advantages of Ergodic Control

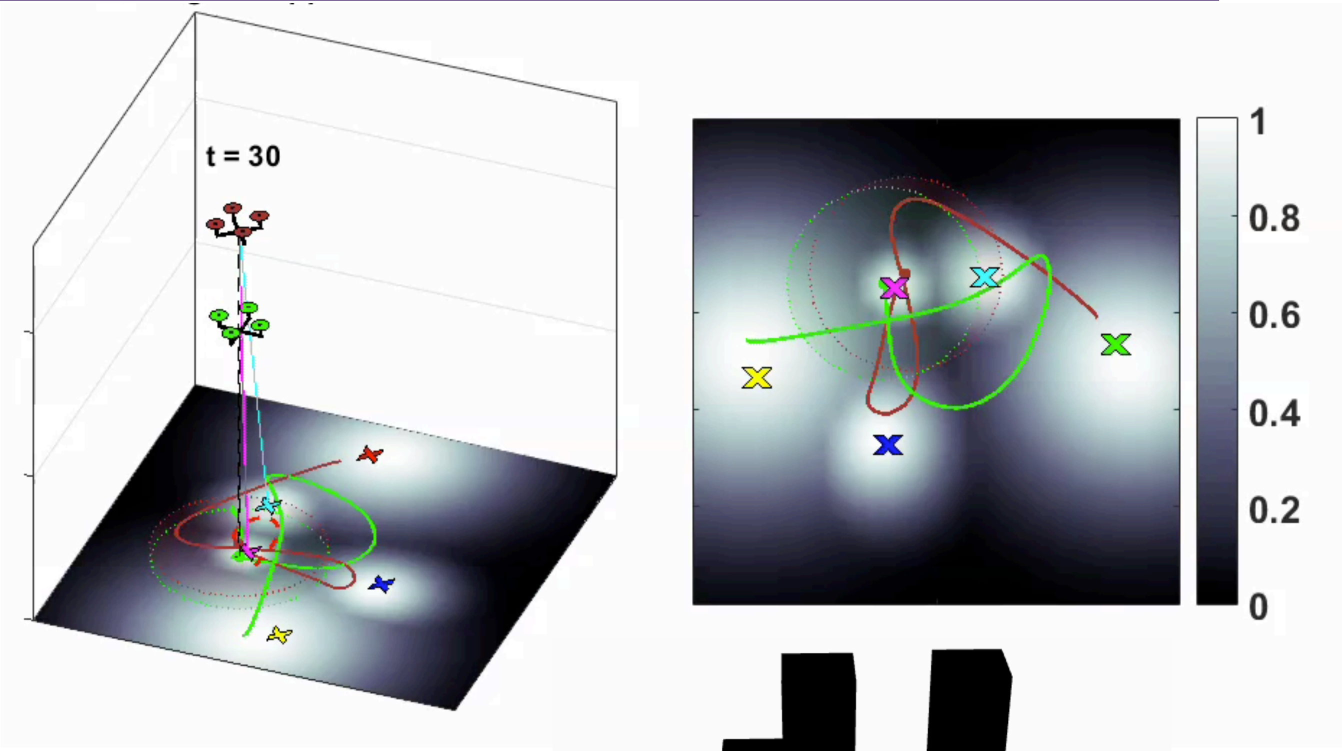


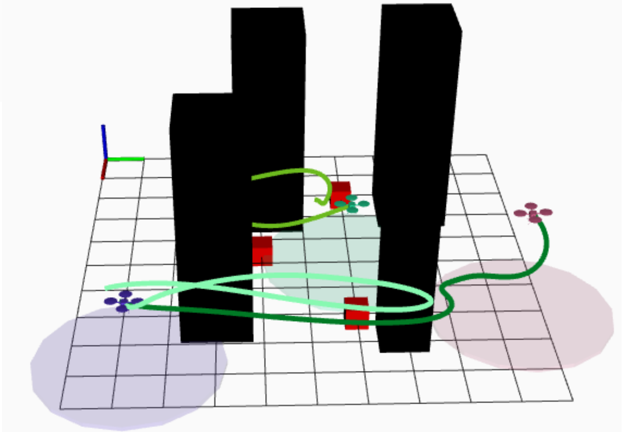


[*] Anastasia Mavrommati, Emmanouil Tzorakoleftherakis, Ian Abraham, and Todd D Murphey. Real-time area coverage and target localization using receding-horizon ergodic exploration. IEEE Transactions on Robotics, 2018.
[*] Ian Abraham and Todd D Murphey. Decentralized ergodic control: distribution-driven sensing and exploration for multiagent systems. IEEE Robotics and Automation Letters,, 2018.

Advantages of Ergodic Control

- Graceful degradation of drones
- Collectively a swarm is more ergodic than individual drones
- Distribution updates from user input



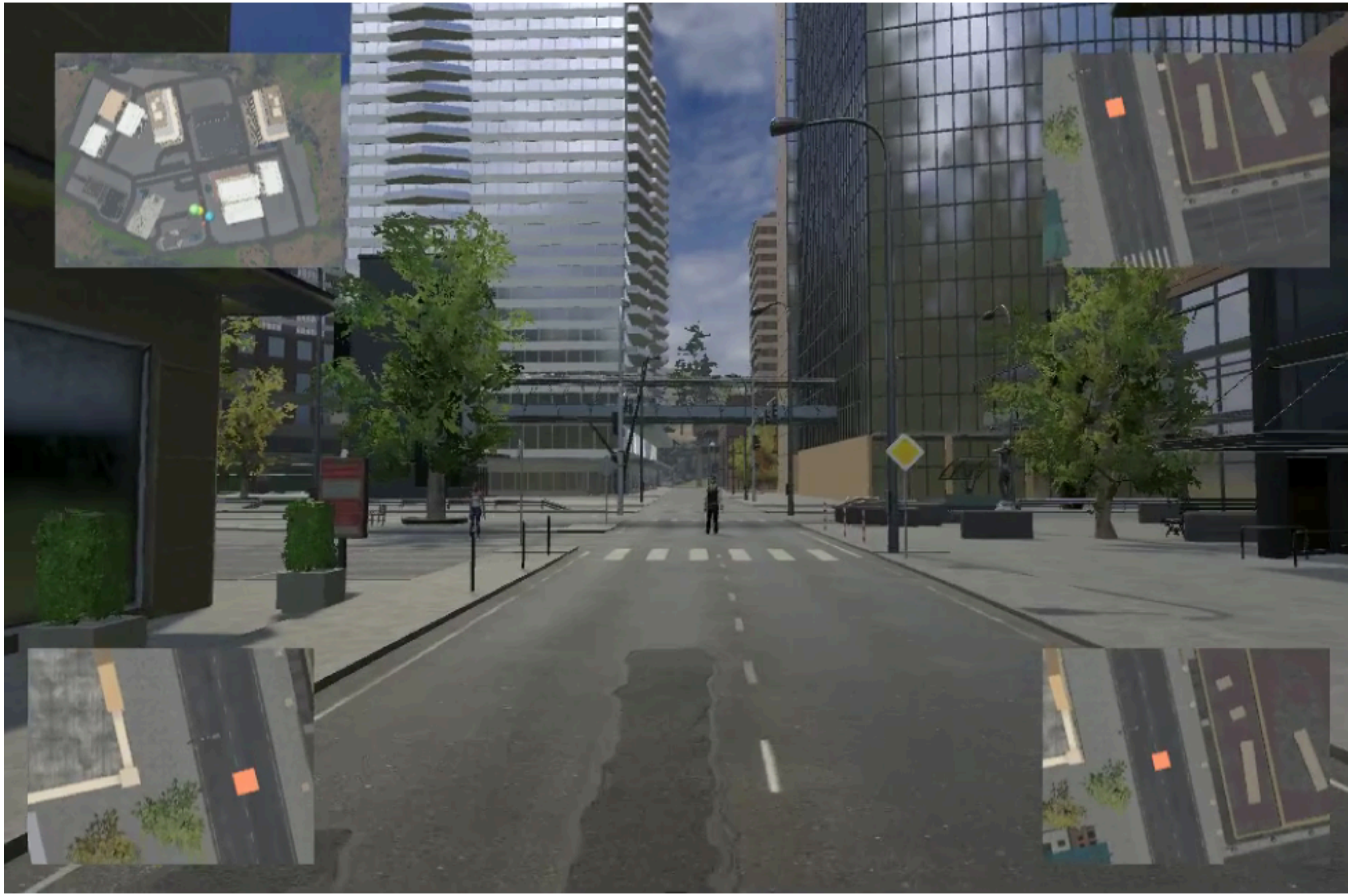


[*] Anastasia Mavrommati, Emmanouil Tzorakoleftherakis, Ian Abraham, and Todd D Murphey. Real-time area coverage and target localization using receding-horizon ergodic exploration. IEEE Transactions on Robotics, 2018.
[*] Ian Abraham and Todd D Murphey. Decentralized ergodic control: distribution-driven sensing and exploration for multiagent systems. IEEE Robotics and Automation Letters,, 2018.

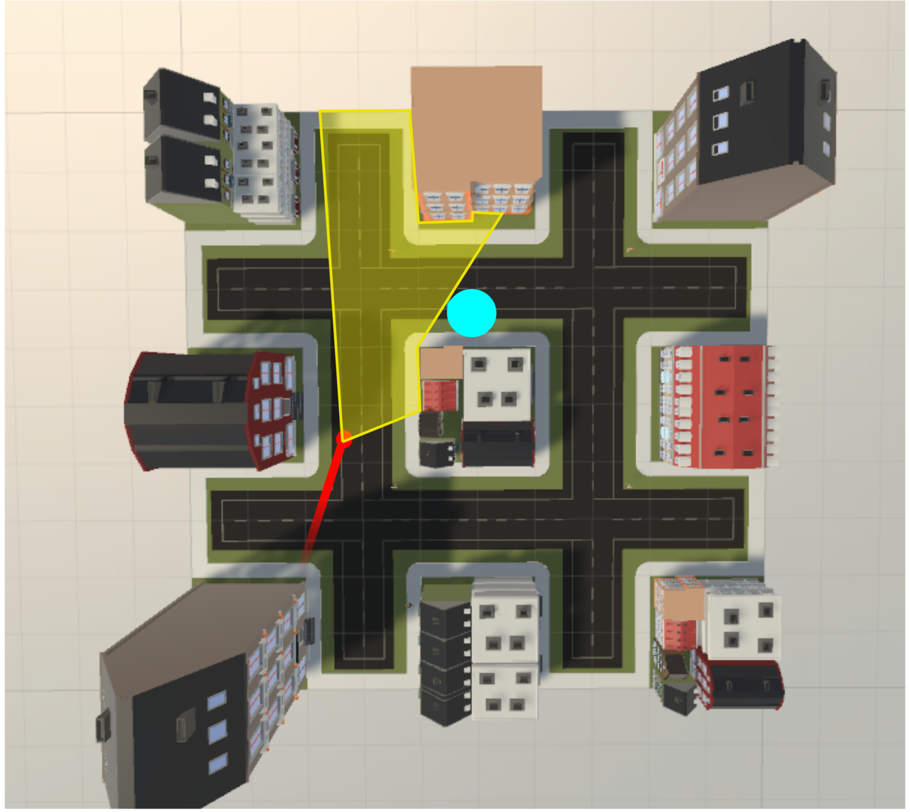
Experimental Methods

Northwestern | McCORMICK SCHOOL OF ENGINEERING

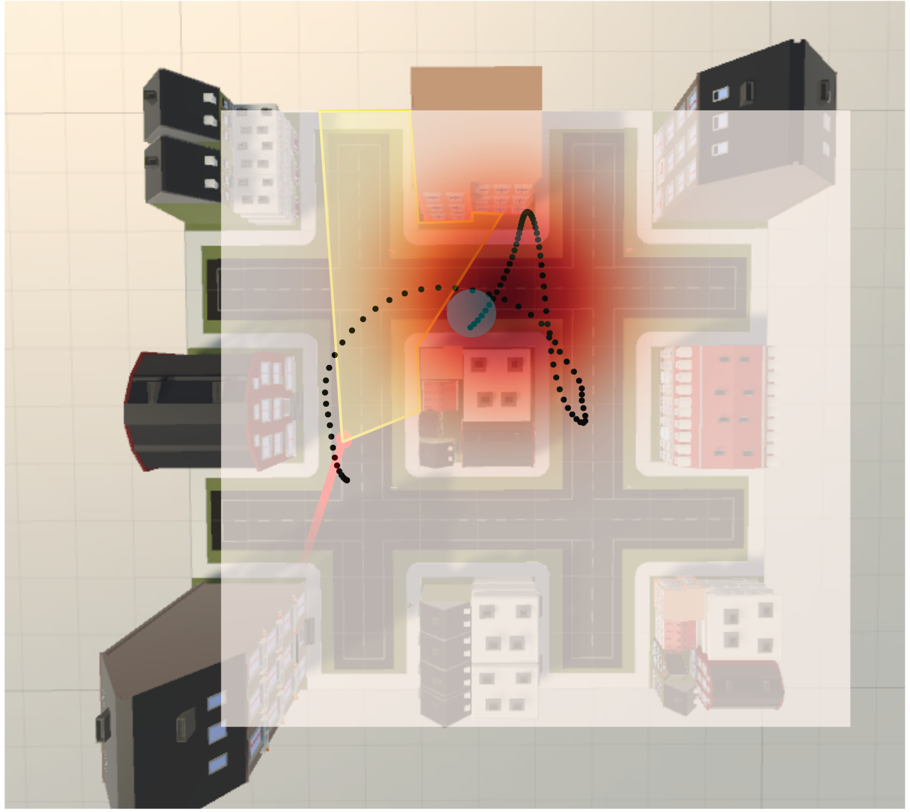
Virtual Reality Environment in Unity



Operator's Perspective: Search and Locate Task

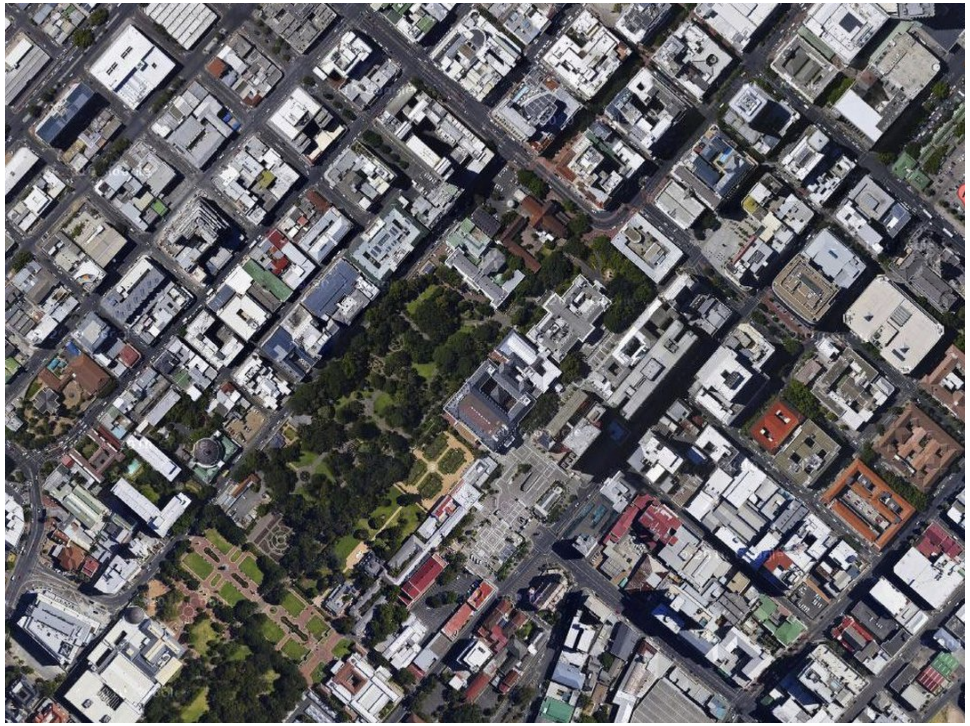


a) Operator with Line-of-Sight (LOS) shown



b) Distribution highlighting LOS occlusion and resulting drone trajectory providing visual aid

Observer's Perspective: ID and Virtual Race Tasks



Identification Task
(accuracy of the prediction)

Virtual Race Task
(time to completion)

Statistical Analysis Using Three-Factor ANOVA

- Level of autonomy allocation
- Number of drones
- Environmental complexity (high vs. low)

	Direct Control		Shared Control		Fully Autonomous	
Single Drone	High	Low	High	Low	High	Low
Swarm	High	Low	High	Low	High	Low

Biometric Data Collection

- Emotiv EPOC Flex EEG signals
- SOMNOtouch PSG
  - continuous blood pressure
  - heart rate
- Pupil Labs eye tracking
  - eye gaze
  - pupil position and diameter

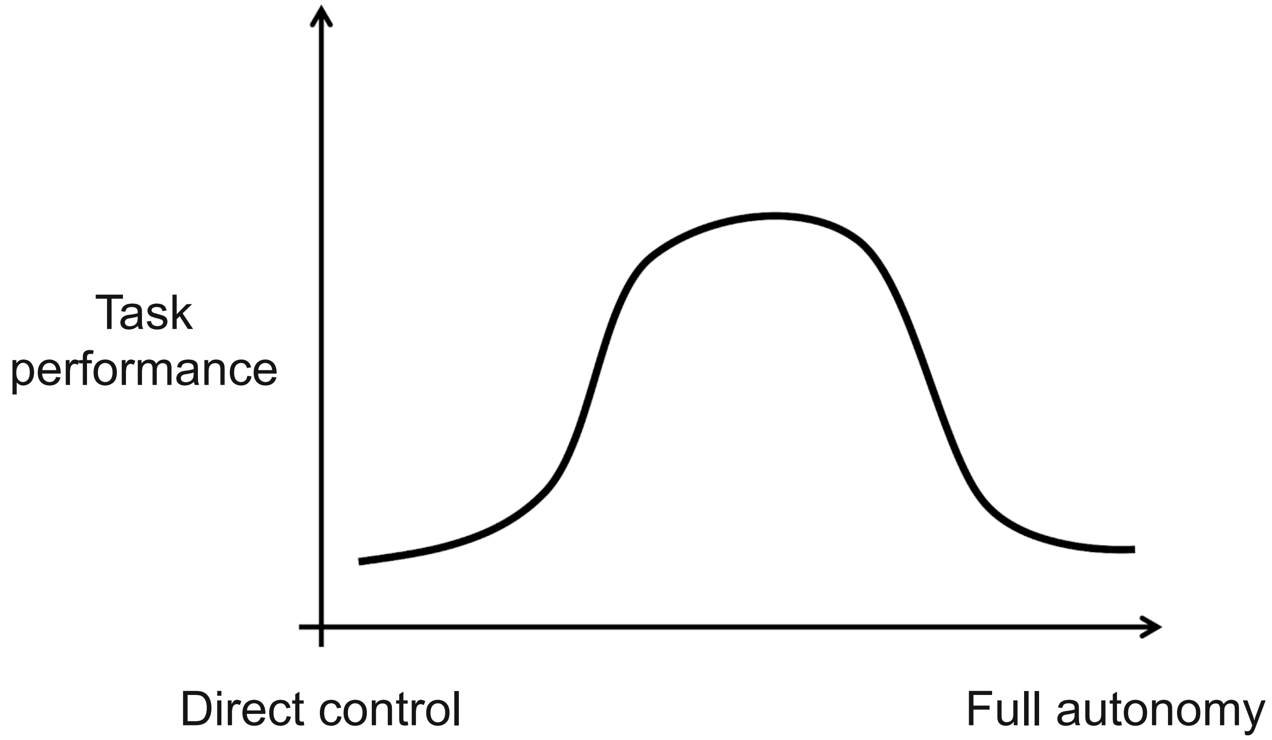
ML model of cognitive availability

SIEMENS

Anticipated Results and Implications for Future Work

Anticipated Results

- Shared control and more drones improves task performance of operator
- Ergodic control decreases task performance of observer
- ML model predicts cognitive availability of operator with high accuracy



Notational figure illustrating anticipated control allocation results

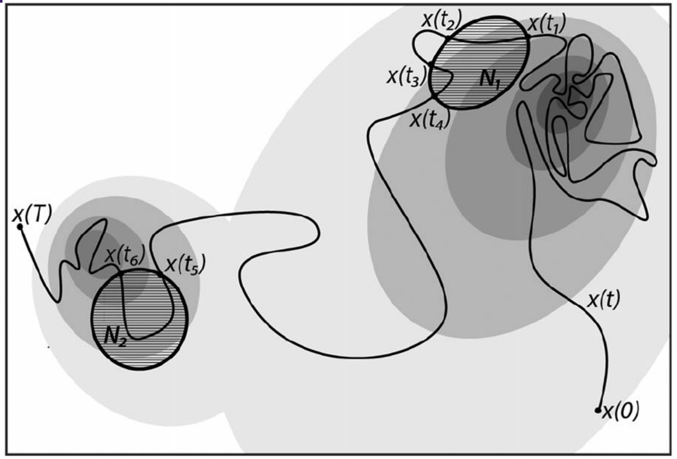
Implications for Future Work

- Allocating appropriate level of autonomy according to cognitive availability of operator
- Integrating with Raytheon or Northrop Grumman hardware
- Field tests using augmented reality (HoloLens)

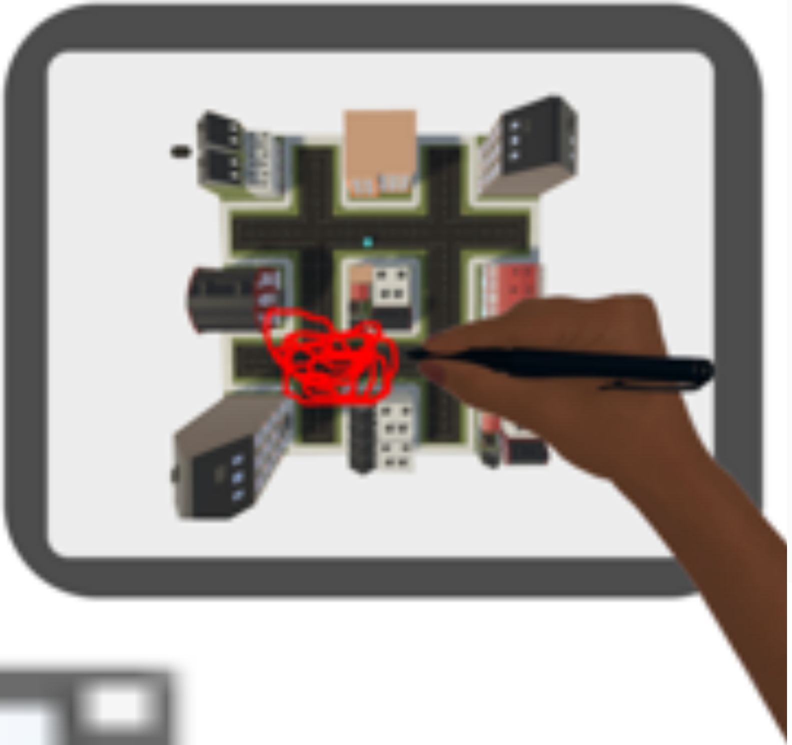
Conclusions

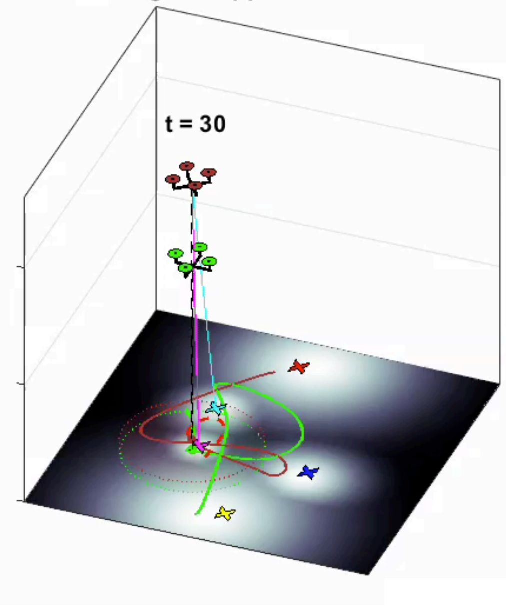
- Operator input specifying areas of interest drives control algorithm
- Improves quality, efficiency, and robustness of robotic exploration
- Leverages capabilities of human and autonomy
- Useful when single operator controls a distributed set of robotic agents

Questions?

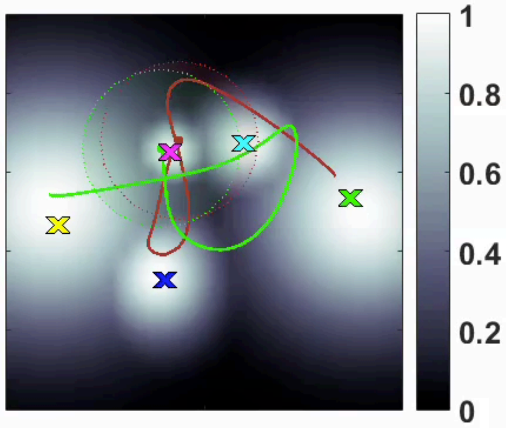


x(t2)
x(t1)
x(t3)
N1
x(t4)
x(T)
x(t6)
x(t5)
N2
x(t)
x(0)

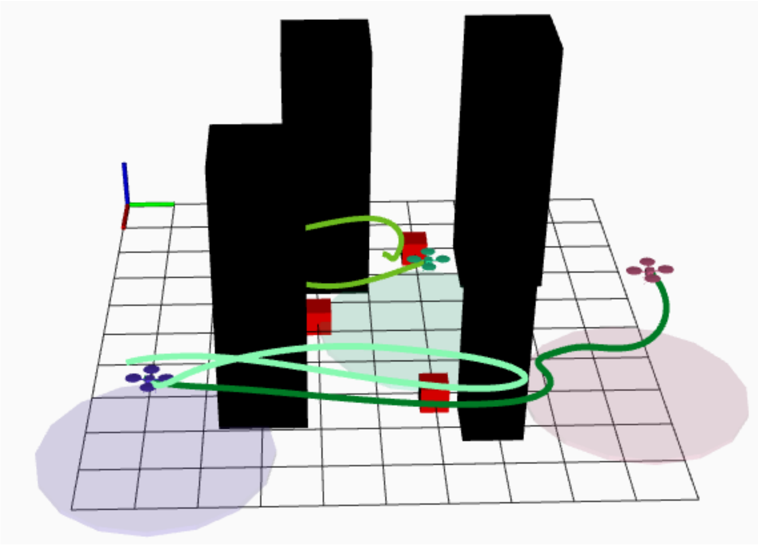


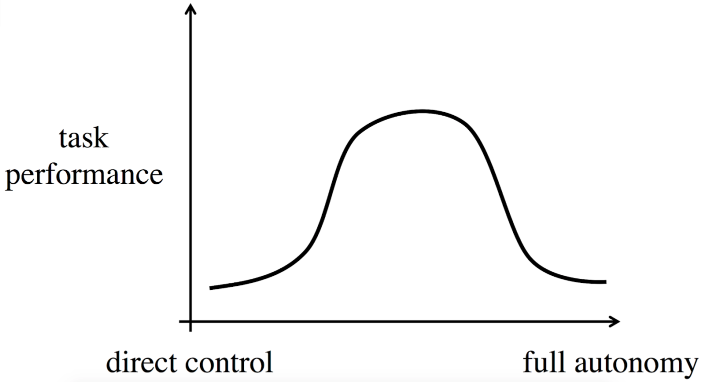


t = 30



1
0.8
0.6
0.4
0.2
0





task
performance
direct control
full autonomy