Resource Constrained Trajectory Design and Data-Driven Control for UAS in Prescribed Burns

Collaborative Research: Integration of Autonomous UAS in Wildland Fire Management

Award #2132798 & 2132799, Jan 01, 2022 – Dec 31, 2025,
Mrinal Kumar (PI) and Roger Williams (Co-PI) [The Ohio State University] and Amit Sanyal (Co-PI) [Syracuse University]

Challenge

- Trajectory planning involves path-dependent integral (resource) constraints, which are NP hard
- Evolving stochastic process (wildfire) presents dynamic, probabilistic ("soft") obstacles and gusting wind disturbances
- UAS autonomy in unstructured uncertainty requires robust V&V leading to certification

Solution

- A novel backtracking graph search is under development and flight testing to handle path-dependent integral constraints
- Physics informed learning is under development in conjunction with evidential reasoning for learning obstacles, their dynamics, and, local wind dynamics
- Rigorous V&V framework for flight testing

Integrated UAS mission design includes novel optimization, fusion, flight testing and certification techniques. Examples shown demonstrate scalable on-board resource constrained path-planning in conjunction with learning of dynamic, probabilistic obstacles, and platform deployment in prescribed burns conducted by the Ohio Department of Natural Resources (ODNR)

Scientific Impact

- This work impacts science of autonomy and multidisciplinary integration of aerial platforms in an unstructured, uncertain and dynamic hazardous environment, with special focus on wildfires and the wildland urban interface (WUI).

Broader Impact

- Integration of autonomous UAS into prescribed wildland burn projects will help understand how topographic, atmospheric and forest fuel factors in temperate hardwood forests influence fire intensity and rate of spread.
- Multi-disciplinary partnerships in research and education will accentuate the right context for autonomous UAS, increasing participation of students in prescribed burns by 2X and create new curricula from K-12 to the graduate level.

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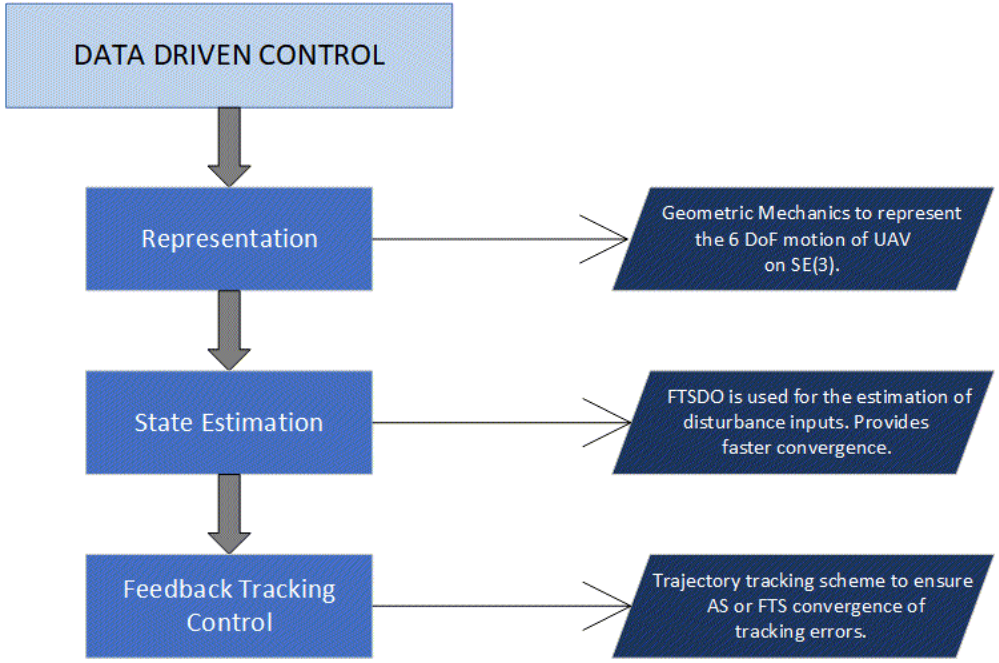
Data-Driven Disturbance Observer
LEAD: Co-PI: Sanyal



Stable Flight Under Strong Disturbances

$$\hat{\chi}^d_{k+1} = \mathcal{D}(e^\chi_k)e^\chi_k + \chi^d_k,$$

$$\mathcal{D}(e^\chi_k) = \frac{((e^\chi_k)^T e^\chi_k)^{1-1/r} - \lambda}{((e^\chi_k)^T e^\chi_k)^{1-1/r} + \lambda}$$

Key Results

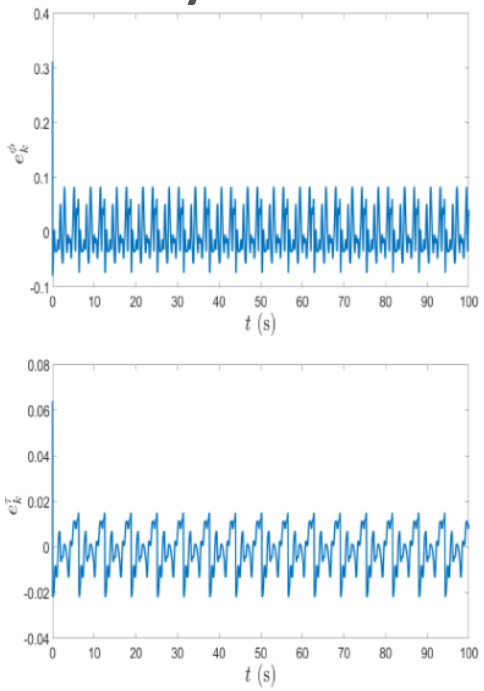


Fig. 1: Model estimation error for (a) disturbance force, and (b) disturbance torque, without noise

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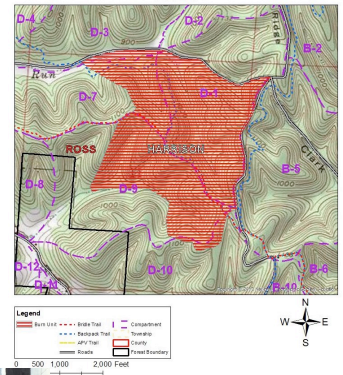
Burn Plan [LEAD: Co-PI: Williams and ODNR]

PRE-BURN
- First trials of the fire behavior study.
- Construct pyrometers that will be used to measure fire temperatures
- Sites identified for the first prescribed fire
- Field work will be performed in the summer, 2022 to install pyrometers, measure physiographic and forest attributes at each pyrometer location and collect fuel information (loading and character)

BURN (OCTOBER/NOVEMBER)
- Conduct first prescribed burn in Fall 2022
- Collect continuous weather information via portable weather station at the burn site

POST BURN (NOVEMBER/DECEMBER)
- Retrieve pyrometers and record fire temperatures
- Data analysis: Fire behavior vs. physiography, forest attributes, fuel attributes, weather conditions.



Burn Site: 2022 (Top Right)
Also shown: past burns, topography, fuel types and instrumentation