NRI 3.0: Innovations in Integration of Robotics
COLLABORATIVE RESEARCH: NRI: Integration of Autonomous UAS in Wildland Fire Management

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Project URL: https://mae.osu.edu/laddcs/research

Scientific Goal: Integration of autonomous unmanned aerial systems (UAS) missions into prescribed wildland burn projects

Challenges

- Impact of Unstructured Uncertainty on Mission Planning: A broken environment presents hard to characterize probabilistic obstacles and ***loads*** that induce path-dependent resource constraints, e.g., heat loading, that make path planning NP hard
- Lack of Trustworthy Environmental Situational Awareness: Multi-source data in a harsh environment is subject to interpretation (hot = fire or ash or hot shrubs?) and has a high conflict rate.
- Gusting Wind Conditions: Aviation weather data does not provide local, micro-level and short-range forecasts needed for reliable operations in a wildfire hazard, with potential for rapid escalation, e.g., firestorms.
- Impact of Environmental Uncertainty on System Integration Flight Certification: Extended beyond visual line of sight (BVLOS) operations, communication delay and loss, poor/intermittent GPS signal

Fig. 1.a. Marion Prairie Burn, 2022

Fig. 1.b. Zaleski State Forest Burn, 2023

Technical Approach

- Build data-driven tools to learn local wind dynamics, and unsupervised clustering tools combined with evidential reasoning to create obstacle and load situational awareness (SA)
- SA information helps model trajectory planning with path-dependent integral chance-constraints, wherein UAS autonomously assumes mission-appropriate risk. We developed novel backtracking techniques to solve resource-constrained path-planning on graphs
- Employ ultra-local disturbance observer models for nonlinearly stable and robust control of platform in hazard
- Conduct controlled wildland fires (prescribed fires) and quantify fire severity, and measure and analyze the influence of forest attributes, land physiography, fuel composition and characterization, and weather conditions on fire behavior.
- During 2022, we demonstrated onboard UAS planning in software-in-the-loop, hardware-in-the-loop and in-situ flight tests over a controlled forest burn (Zaleski State Forest).
- Data sets generated during each stage of a prescribed burn's lifecycle will be employed to develop improved fire forecasting models that are to be used by practitioners.

Fig. 2. Walking survey to identify Rx fire plot (May 2022)

Scientific Impact

- This work impacts science of autonomy and multidisciplinary integration of aerial platforms in an unstructured, uncertain and dynamic hazardous environment.
- This project brings into focus the wildland urban interface (WUI) in the Eastern United States. This research will create new discoveries related to the nature of impact of topography, weather, and fuel parameters on fire behavior. It will provide avenues of fire mitigation in the future as climate change will lead to increased fires in the eastern USA of severe intensity
- This project will create a framework for learning the fire environment (heat loading, gusts, smoke, etc.) using machine learning tools developed in a framework of evidential reasoning, to create meaningful outcomes despite ambiguity and sensor conflict
- This project will develop scalable solutions for onboard autonomous mission planning in unstructured uncertainty. We aim to build an autonomous aerial platform that is certified for surveillance operations in a prescribed burn.
- Data-driven control schemes developed in this project will provide guaranteed stability and robustness in autonomo[us] operations with actuator constraints in an environment with unmodeled disturbances

Fig. 5. The new BB-X series of autonomous aerial platforms (shown: BB-2)

Fig. 3a. Sample from Maple dataset for automatic classification of foliage (July 2022)

Fig. 3.b. Sample from Oak dataset for automatic classification of foliage (July 2022)

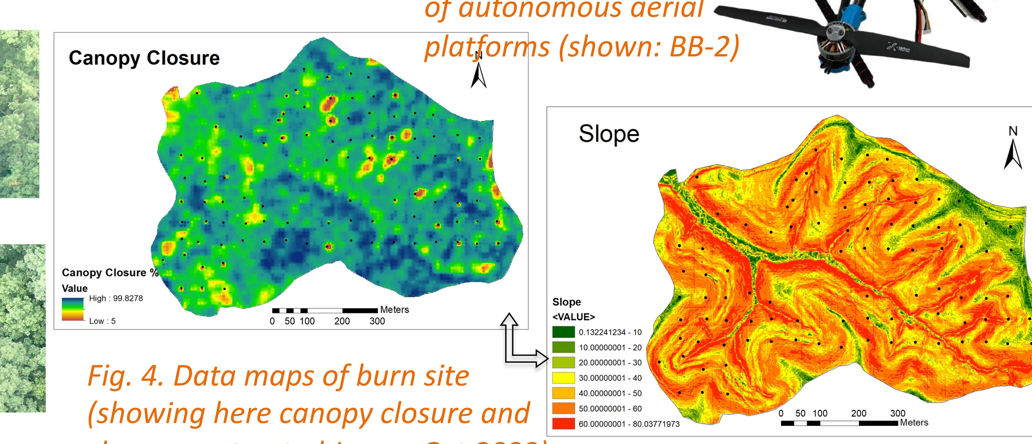

Fig. 4. Data maps of burn site (showing here canopy closure and slope, constructed June – Oct 2022)

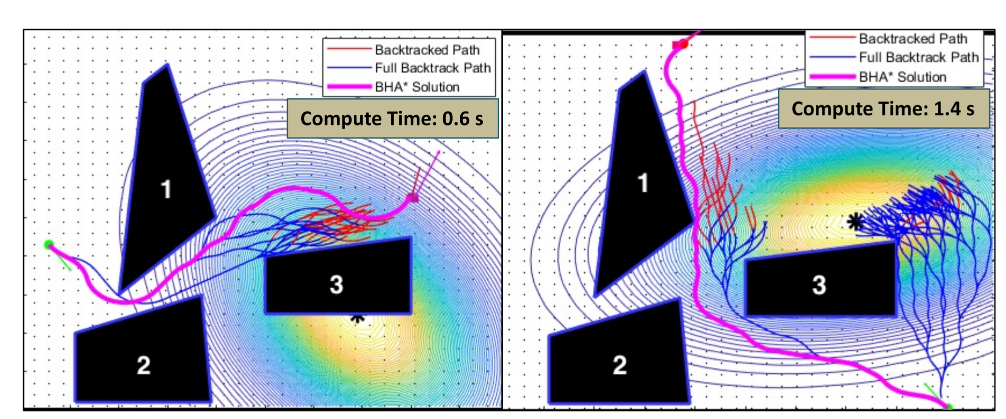

Fig. 6. Backtracking Graph Search (shown here in pink with hybrid A) achieves high quality trajectories in a computationally scalable manner*

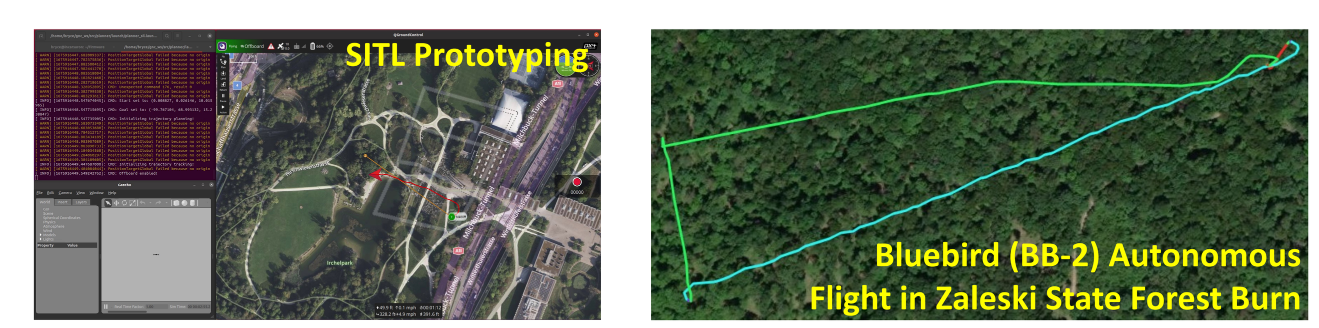

Fig. 7. (LEFT): Software in the Loop (SITL) testing achieves rapid prototyping, using a desktop emulation of the PX4 flight stack interacting with Gazebo quadrotor dynamics, with a concurrently running MAVROS node and Q-GroundControl (QGC). SITL is followed by Hardware in the Loop (HITL) tests, where PX4 runs on a PixHawk 6C Flight Control Unit. (RIGHT): BB-2 performs a successful autonomous flight in the Zaleski forest burn, returning IR video of the fire-front. Guidance goals were sent from QGC via telemetry radio. Flight was BVLOS. Next step is to achieve autonomous, on-board guidance goal selection.

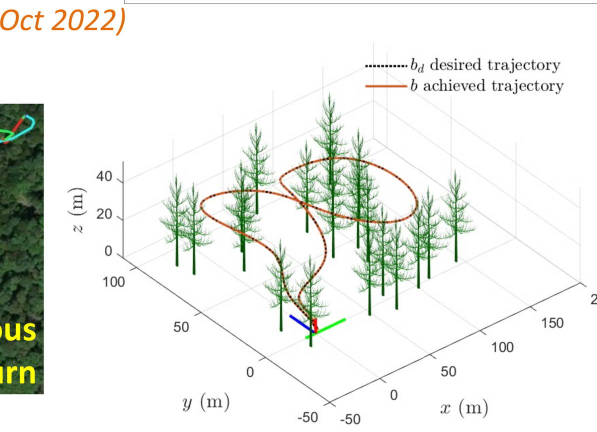

Fig. 8. Robust position tracking feedback control assisted by a finite-time stable disturbance observer, allowing stable flight in fire conditions. Vehicle trajectory achieves convergence to a bounded neighborhood of the reference trajectory.

Broader Societal Impact

STAKEHOLDERS

- Entire population living along the Wildland Urban Interface (WUI) in the Eastern United States
- Fire management and suppression units
- Participants in integration of UAS into maintenance of natural and man-made infrastructure. Examples: Ohio Department of Natural Resources, OH-DOT, Division of Forestry

RELATED USE CASES

- Applications involving unstructured phenomena & environments with poorly modeled dynamics or anomalous sensor interactions. Examples include space and cislunar domain awareness (S/CDA), surveillance tracking, and disaster response.

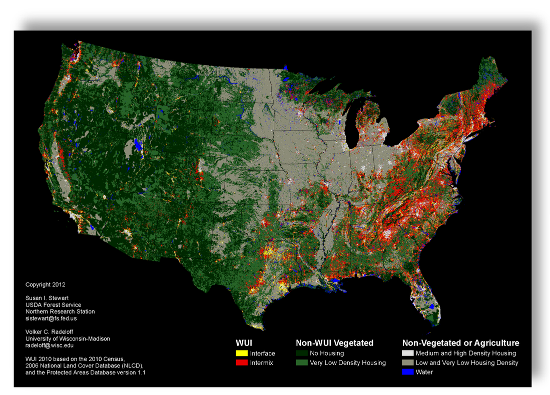

Fig. 9. The wildland urban interface (WUI) along the Eastern USA.

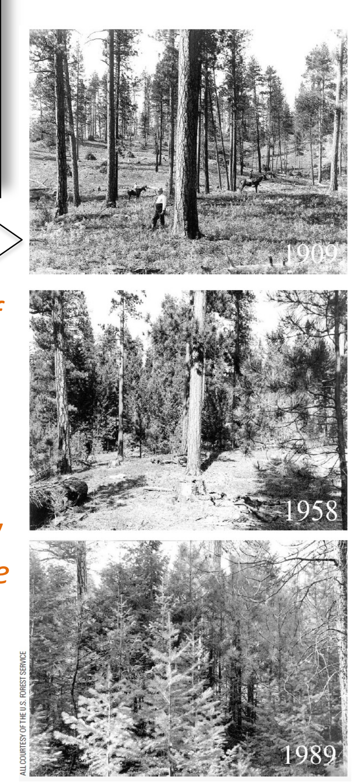

Fig. 10. Restoring health of the forest and wildfire-dependent ecosystem by careful reintroduction of fire. Wildland ecosystem health has catastrophically deteriorated in the absence of regenerative benefits of periodic fire. (Image Courtesy: Forest History Today, Spring 2008)

Educational and Outreach Impact

- Engage K-12 teachers and students through curriculum development (short courses), summer events and internships (2 high-school interns in 2022-23)
- Develop cross-disciplinary educational material. We participated in OSU's Course Design Institute (CDI- Summer 2022) to develop the structure and content of "Robotic Missions in Wildland Fires". This project helped sponsor one Capstone project at Ohio State, resulting in development of BB-3 (Fig. 4).
- Student led public awareness projects (podcast production) in partnership with NPR, supported partially by a BATTELLE Endowment Grant

Broader Impact

- Create scalable algorithms for solving resource constrained planning problems (gains in excess of 100X speed up over state of the art)
- Increase student participation in prescribed burn projects by 2X
- Improve wildfire propagation models in key metrics including flame length and rate of spread

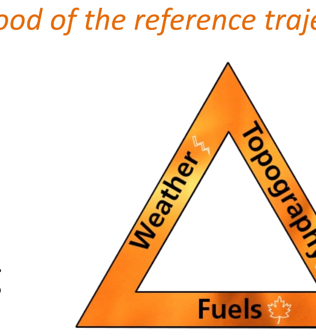

Fig. 11. This project will identify key indicators of fire behavior and correlate them with fuel, weather, and topographic features.