Overview

We propose a collaborative, multi-disciplinary research program focused on the integration of autonomous unmanned aerial systems (UAS) into prescribed wildland burn projects. This work brings together experts from the areas of forest management and ecology, uncertainty quantification, evidential sensor fusion and data-driven modeling and control, to enable autonomous aerial robotic systems to integrate with and assist humans in an unstructured, uncertain and hazardous fire environment. Integration is targeted during pre-burn reconnaissance, burn monitoring and control, and, post-burn survey. We expect to minimize the risks involved to human agents by providing real time situational awareness and prognostics of fire evolution. In the long term, this work will aid in the management of the wildland-urban interface, monitoring and suppression activities of unplanned wildfires as well as other hazardous phenomena. It is also expected to help improve wildfire forecasting models through retrospective data analysis.

Keywords: Planning, Control, Learning, Robustness, Environmental Monitoring

Intellectual Merit

- Quantification of Unstructured Uncertainty: A complex environment presents hard to characterize obstacles that induce resource (integral) constraints, e.g. heat loading or other perceived threats. Path dependent resource-chance-constrained path-planning problems are NP hard and not been considered in the literature. We will formulate and solve these problems, allowing the autonomous agent to deliberately assume mission appropriate risk. This will enable the discovery of "keyhole trajectories," through which highly cost-effective paths can be found.
- Learning Evidence for Environmental Situational Awareness: Multi-source data in a harsh environment is subject to interpretation and has a high conflict rate. We will construct belief functions that accurately reflect sensor ignorance contained in hypotheses related to the environment. Evidential information fusion will effectively handle sensor epistemic uncertainty and allow reliable integration in an environment where not all data is trustworthy.
- Robust, Real-Time Data-Driven UAS Control: Reliable operation of autonomous vehicles with uncertain dynamics requires nonlinearly stable and robust learning of unknown inputs even without prior training data or persistent excitation. We will achieve computational efficiency, speed and accuracy in learning the unknown (disturbance) inputs through the design of Hölder-continuous and finite-time stable disturbance observers and data-driven control schemes. The unknown (disturbance) force and torque inputs will be represented using an ultra-local model. These schemes will provide guaranteed stability and robustness in autonomous operations of UAS with uncertain but Lipschitz-continuous dynamics, if the control constraints are met.
- Fire Prognostics for Eastern Forests: The majority of research on wildland fire behavior has focused on western forests, and less so on eastern forests. Differences in forest composition and structure, and differences in fuel composition and characteristics may translate into differences in fire behavior. This work will help to delineate any differences as well as similarities of fire behavior between eastern and western forests.

Broader Impacts

Our proposed partnership in research and education accentuates the right context for autonomous UAS, namely, taking humans out of missions that involve danger and/or repetitive, stressful actions. The science developed in this project will benefit UAS platforms in fire monitoring, as well as applications involving other unstructured phenomena/environments with poorly modeled dynamics and/or anomalous interactions between sensors and their objects of interest. Examples include space and cislunar domain awareness (SSA), surveillance tracking, disaster response etc., where environmental uncertainty and/or unpredictable target behavior can create misleading or contradictory data. Our cross-disciplinary education and outreach activities will train students on how best leverage autonomous UAS to manage fuels in the wildland-urban interface.