NRI 3.0: Innovations in Integration of Robotics

Integration of Autonomous UAS in Wildland Fire Management

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Project Abstract

The wildland-urban interface (WUI) is now the fastest-growing land use in the United States. Future fire probability forecasting shows dramatic increases in probability of catastrophic fire in parts of the eastern U.S. due to climate change, combined with rapidly increasing WUI. More attention is needed to understand the factors of fire behavior and spread in eastern forests. This multi-disciplinary research program is focused on the integration of autonomous unmanned aerial systems (UAS) into prescribed wildland burn projects to understand how topographic, atmospheric and forest fuel factors in temperate hardwood forests influence fire intensity and rate of spread. Experts from the areas of forest management and ecology, uncertainty quantification, sensor fusion and data-driven modeling and control will collaborate to deploy autonomous aerial robotic systems in unstructured, uncertain, and hazardous fire environments. 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. Multi-disciplinary partnerships in research and education will accentuate the right context for autonomous UAS, namely, taking humans out of missions that involve dangerous and repetitive actions. Research activities will strengthen and diversify stakeholder involvement, including state departments of natural resources, firefighting communities, and K-12 education.

The scientific merit of this research is anchored in the advancement and integration of autonomous unmanned aerial systems with wildland fire management projects. Theoretical, computational, and experimental methods and materials developed in this work will enhance situational awareness and enable autonomous risk-aware decision making in the face of unstructured uncertainty in a hazardous environment. UAS path planning will formulate and solve novel resource chance-constrained optimization problems. UAS will bypass computational heavy lifting to generate in-time micro-level local conditions by enabling physics-informed learning through Koopman operator theory. New sensor belief functions will be designed that accurately reflect sensing ignorance contained in hypotheses related to the fire environment. Evidential information fusion will effectively handle sensor epistemic uncertainty and allow reliable integration in an environment where not all data is trustworthy. Data-driven control will enable efficient and reliable operation of autonomous vehicles with uncertain dynamics in real time by using available knowledge of applied inputs and observed outputs, to learn the unknown inputs even without prior training data or persistent excitation. Real-time estimates of disturbance forces and torques acting on an UAS obtained by the disturbance observer will provide information on the turbulence and air flow around a wildland fire region. Finally, most of the 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.