NRI INT: Safe Wind-Aware Navigation for Collaborative Autonomous Aircraft in Low Altitude Airspace

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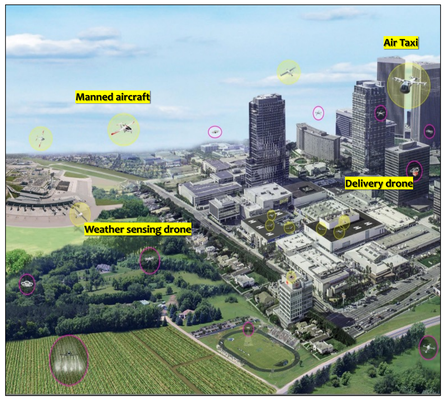
Background and Challenges

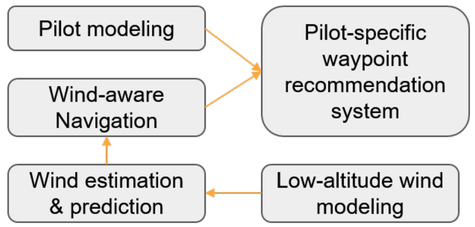
- Small unmanned aircraft systems (sUAS) technologies found many civil, commercial, and military applications.
- Infrastructure, such as NASA UAS traffic management (UTM) for low-altitude airspace management and monitoring, is being developed.
- Safety and efficiency of sUAS operations are strongly impacted by low-altitude gusts:
  - Negatively affect pilot operations, reduced flight time, damage.
  - Airspace management and allocation made conservative and inefficient.

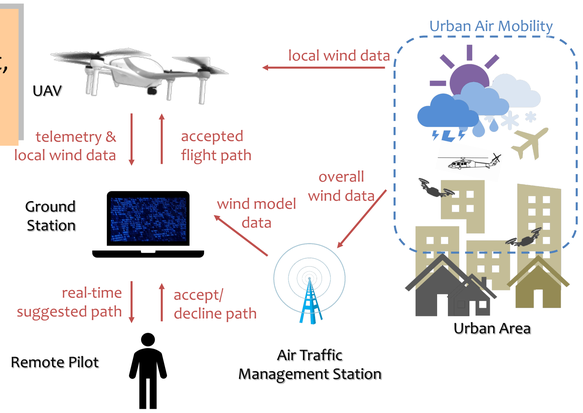
Improve safety and efficiency of low-altitude UAS operations



Technical Approach

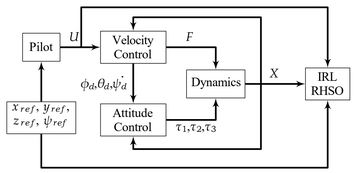
'In-time' or 'real-time' wind field information, communicated effectively to pilots and traffic management, can enhance safety, efficiency, and robustness of future sUAS operations in low-altitude airspace.

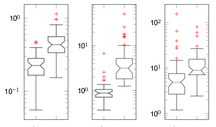




Progress and Contributions

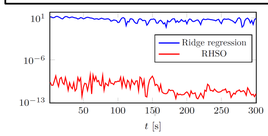
Pilot intent modeling: simulation study





(a) $SD = 0.01$ (b) $SD = 0.1$ (c) $SD = 0.5$

Inverse reinforcement learning with noisy data: A Kalman filter like implementation of the RHSO was found to be more effective than a fixed-gain implementation of the RHSO.



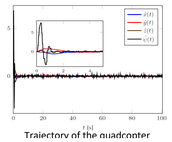
Comparison between policy estimation errors obtained using RHSO and offline batch ridge regression

Summary of contributions:

- Developed a ridge-regression-like online observer that converges to the subspace of solutions of underdetermined linear systems
- The observer drives a suitably defined pilot intent equivalence metric to a neighborhood of the origin
- Novel data-sufficiency conditions guarantee convergence to equivalent solutions

Pilot intent modeling: experimental validation

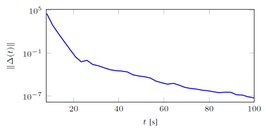
(Identification of the cost function of an LQR sUAS pilot)



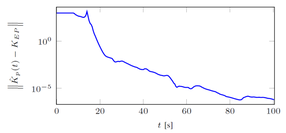
Trajectory of the quadcopter

	RHSO	HSO
Mean $\|\ E_P - \hat{\ }_P\|$	2.6997e-08	NaN
Cov $\|\ E_P - \hat{\ }_P\|$	8.3316e-15	NaN

The HSO in Self et al., 2020 diverges, but the RHSO in Town et al., 2022 converges when applied to the surrogate pilot cost function identification problem.



Convergence of the equivalence metric



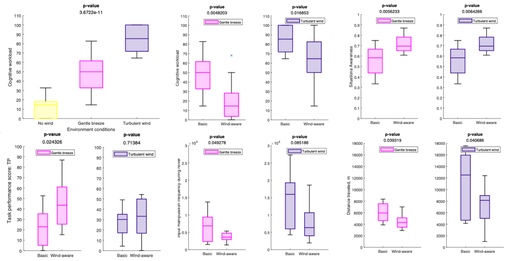
Convergence of the estimated policy

Progress and Contributions

Pilot-in-the-loop experiments

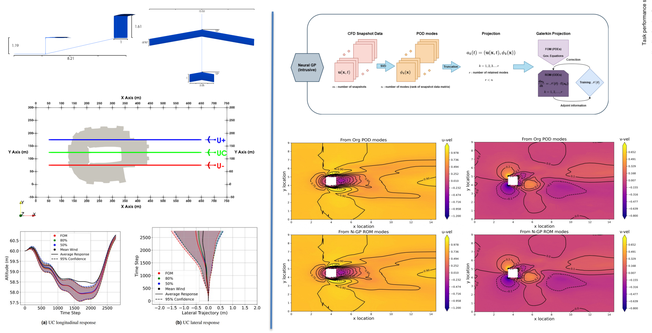
Mission: survey & take photos

- A total of 11 participants (varying experience)
- Assessment: subjective, objective
- Observations: increased confidence due to the wind-aware display; wind direction is more helpful than magnitude to the pilots.



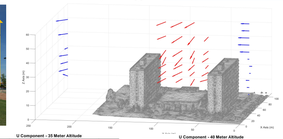
Wind modeling, simulation and prediction

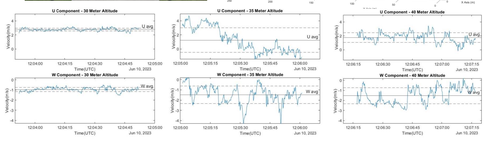
- NASA Advanced Air Mobility (AAM) vehicle simulation in reduced order wind
- Lightweight Neural Galerkin Projection ROM



Quadcopter wind estimation

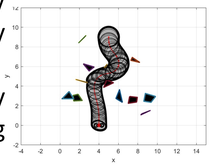
- Experimentally validated invariant-EKF for wind estimation, outperforming other filters (e.g., EKF, MEKF)
- Experimental wind mapping





Wind-aware quadcopter control

- Robust wind aware trajectory planning using a funnel library approach
- Proof-of-concept simulation study with temporally and spatially varying wind disturbances



Scientific and Broader Impacts

- 17 graduate students benefited from this project to date, 3 REUs (2 from minority groups) involved.
- New course materials for estimation and robotics.
- Enhanced simulators in AirSim and ROS.
- Scientific ML workshop to disseminate knowledge
- Involved pilots from diverse background (e.g., engineering, aviation education) for research.
- Computational resources and participation in field tests from NCAR.
- Improving low-altitude wind prediction towards precise micrometeorology and sensing.
- sUAS integration into the National Airspace, particularly challenging low-altitude urban environments.
- Impacts on UTM and Advanced Air Mobility (AAM) efforts, package delivery, etc.
- Contribute to future aviation networks and other applications, e.g., sUAS-assisted wireless communication, first response, etc.

2024 FRR & NRI Principal Investigators' Meeting
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