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

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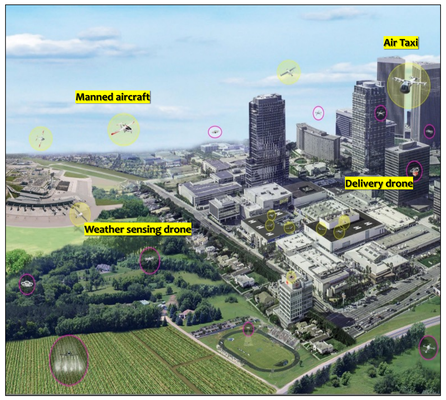
Background and Challenges

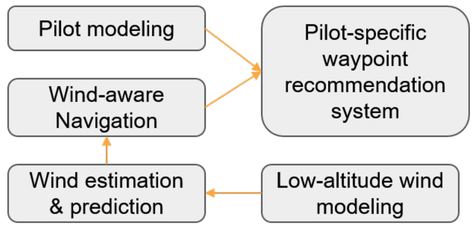
- Small unmanned aircraft systems (sUAS) technologies found many civil, commercial, and military applications.
- Infrastructure, such as NASA UAS traffic management (UTM) for low-altitude airspace management and monitoring, is being developed.
- Safety and efficiency of sUAS operations are strongly impacted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

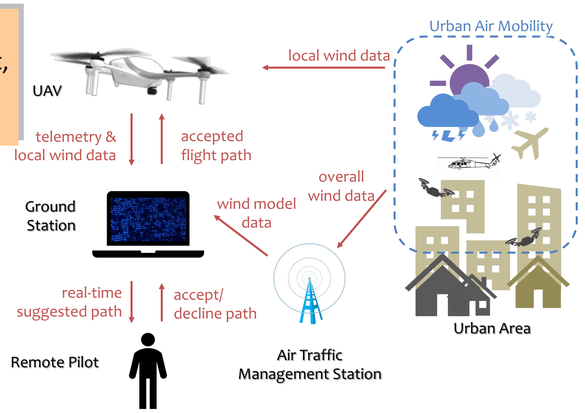
Improve safety and efficiency of low-altitude UAS operations



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.



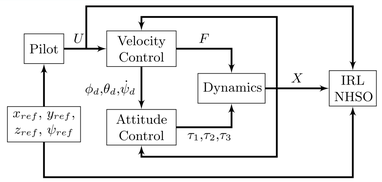


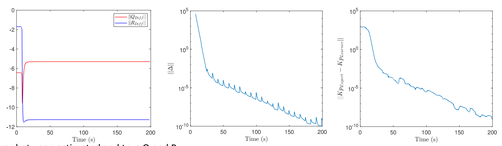
Progress and Contributions

Pilot intent modeling

- New insights into uniqueness of solutions of the inverse reinforcement learning (IRL) problem:
  - *Equivalent solutions:* Cost functions with the same feedback policy as the expert, generate identical optimal trajectories, and hence, are indistinguishable
- New observer architecture and analysis techniques:
  - Designed to drive a suitably defined equivalence metric to a neighborhood of the origin
  - Novel data-sufficiency conditions guarantee convergence to equivalent solutions

- Experiments: sUAS commanded to a waypoint via a virtual pilot (LQR)

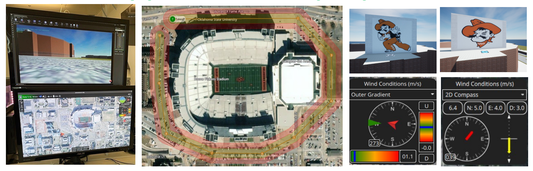


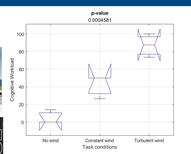


Error between estimated and true Q and R in the cost function | Norm of the equivalence metric | Feedback estimation error

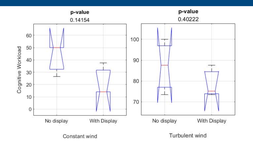
Progress and Contributions

Preliminary pilot-in-the-loop experiments

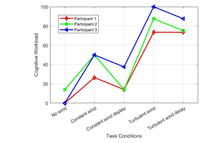




Wind does not increase cognitive load?

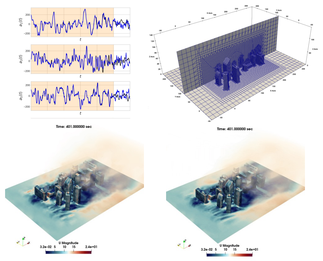


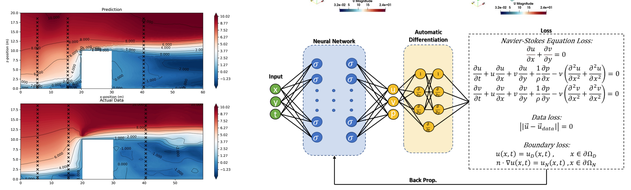
Wind information display does not increase operators' cognitive load?



Wind modeling, simulation and prediction

- Non-intrusive ROM: POD + LSTM for a 3D urban simulation
- Physics informed neural networks (PINN) for 2D urban flows: vertical LiDAR like data from CFD





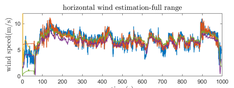
Wind-aware quadcopter control

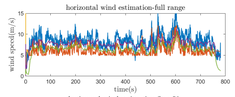
- Data-driven approaches to control quadcopters with wind and rotor dynamics
- Parameterized input inference for stochastic optimal control with safety constraints

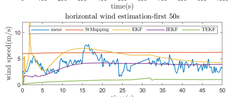
	Average error value	Reduction from LQR (%)
LQR	0.6812	-
LQR+ K-MPC 1 [without gamma (mean wind)]	0.6136	9.92%
LQR+ K-MPC 2 [without gamma (constant wind)]	0.6267	8.00%
LQR+ K-SMPC with gamma	0.4656	31.65%

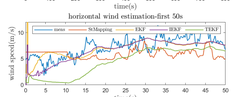
Quadcopter wind estimation

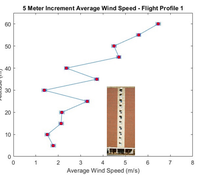
- Experimentally validated wind estimation algorithms
- Developed platforms to conduct data collection and flight tests.

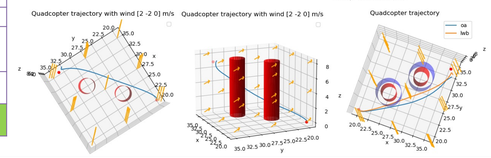












Scientific and Broader Impacts

- Wind field data compression using neural networks can result in significant reduction in computational cost for pilot decision making and predicting adverse wind patterns in complex urban setup.
- Improving low-altitude wind estimation, prediction towards precise micrometeorology and atmospheric sensing.
- Enhanced simulators in AirSim and ROS.
- Scientific ML workshop to disseminate knowledge
- sUAS integration into the National Airspace, particularly challenging low-altitude urban environments.
- Impacts on UTM and Urban Air Mobility (UAM) efforts, package delivery, reconnaissance, etc.
- Contribute to future aviation networks and other applications, e.g., sUAS-assisted wireless communication, first response, etc.
- Involved undergraduate and pilots in the research

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