CPS: Medium: Data-Driven Adaptive Real-Time (DART) Flow-Field Estimation Using Deployable UAVs

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Motivation:

The Fukushima Daiichi nuclear disaster and the Aliso Canyon natural gas leak are recent high-profile examples of emergency situations that resulted from the unplanned release of an airborne contaminant. In such emergency scenarios, accurate real-time prediction of contaminant movement is invaluable for planning emergency response, protecting emergency workers, and assessing environmental impact. However, accurate prediction of contaminant dispersion is challenging because of atmospheric turbulence, ground terrain topology, and changing wind conditions. This project addresses the problem of predicting atmospheric contaminant dispersion in real time by using a fleet of autonomous fixed-wing unmanned air vehicles (UAVs) to obtain sparse physical measurements of the atmospheric flow and contaminant concentrations. Then, these sparse physical measurements are used in real time to continually improve a computational fluid dynamic (CFD) model in order to produce an accurate real-time prediction of the contaminant dispersion. **The primary aim of this project is to develop and demonstrate a new data-driven adaptive real-time (DART) system that produces accurate real-time micrometeorological estimates and forecasts contaminant dispersion near its source.** The DART system will consist of a CFD cyber system and a physical system of autonomous fixed-wing UAVs instrumented with flow sensors and contaminant-concentration sensors. Together, this DART system will produce accurate flow-field estimates, which can be used to predict contaminant dispersion.

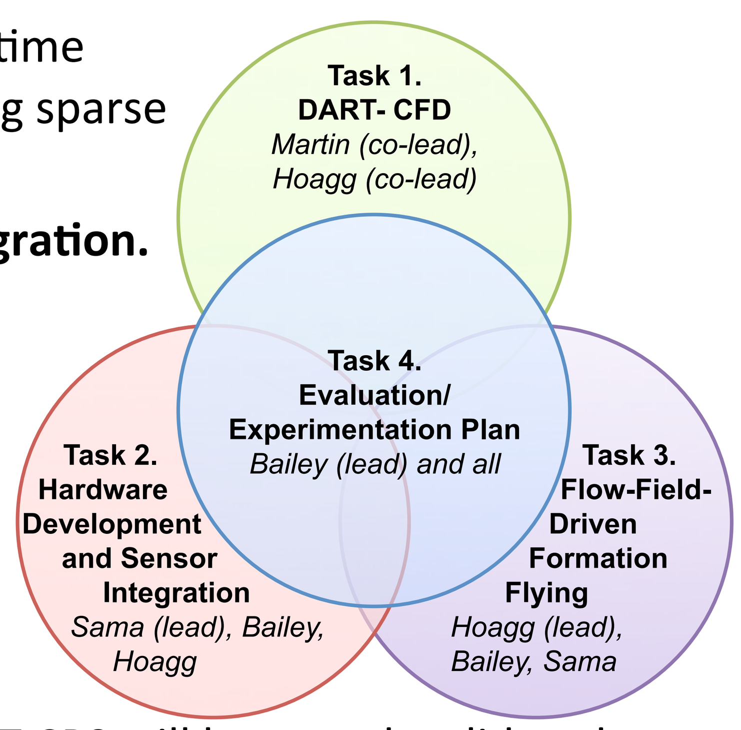
Project Overview

Objective: To develop and demonstrate the new DART flow-field-estimation CPS

Task 1. DART-CFD. Develop DART-CFD for real-time prediction of airborne pollutant dispersion using sparse physical measurements obtained by UAVs

Task 2. Hardware Development & Sensor Integration. Develop a UAV-based system for measuring atmospheric flow and pollutant concentrations

Task 3. Flow-Field-Driven Formation Flying. Develop new formation flying methods for taking distributed flow field and concentration measurements. Methods will use DART-CFD cyber feedback



Task 4. Evaluation/Experimentation Plan. DART CPS will be tested, validated, and evaluated in 3 experimental phases:

- i) Off-line validation of DART-CFD using data obtained from UAVs
- ii) Online validation of DART-CFD using wind tunnel data
- iii) Full-scale DART CPS demonstration

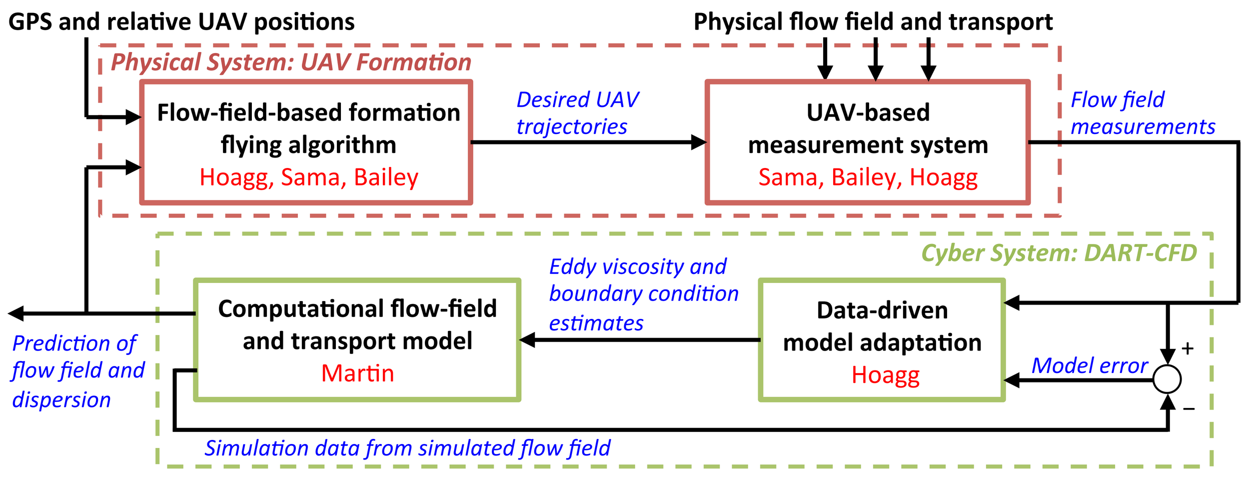
Scientific Impact

Project addresses the difficulty of predicting atmospheric contaminant dispersion in real time. Tackling this challenge requires:

1. New techniques for real-time data-driven model adaption (i.e., DART)
2. Advances in CFD turbulence modeling
3. Improvements in UAV-based sensing and data processing
4. New cyber-feedback-based UAV formation flying methods

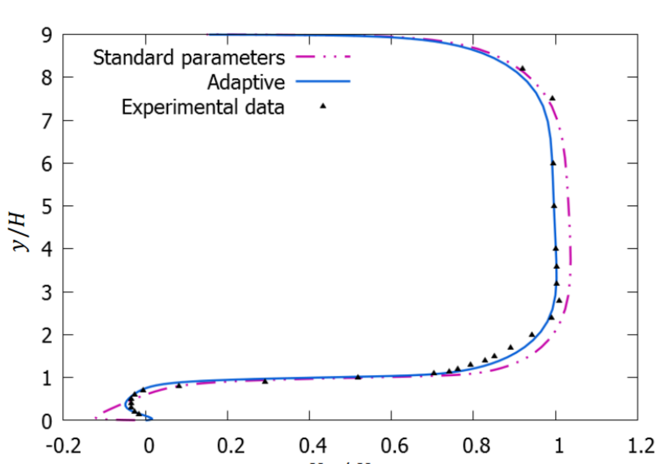
These advances could have application to other CPS, which require either data-driven model adaptation, turbulence modeling, distributed sensing, or cyber-feedback-based cooperative control of autonomous vehicles

Schematic diagram of the DART flow-field estimation CPS. Project focuses of the CPS areas of control, autonomy, and real-time systems



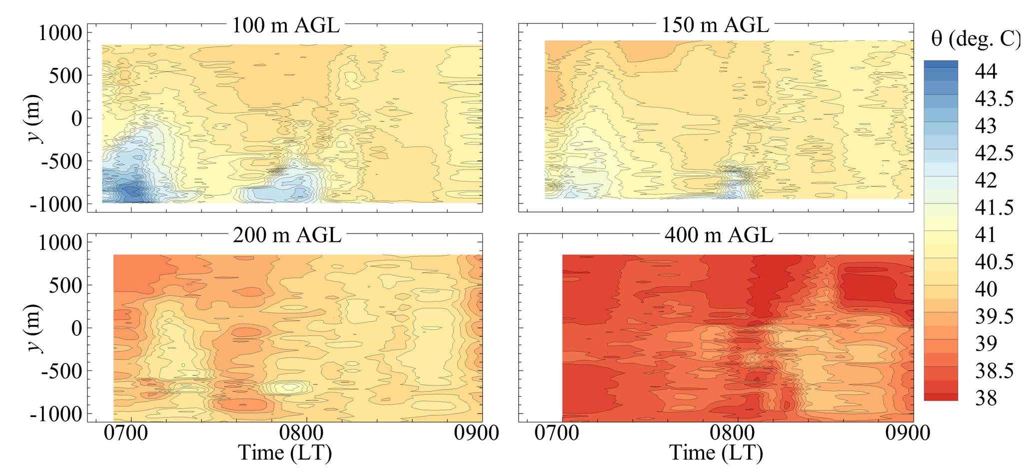
Technical Approach

DART-CFD: Adopts algorithms from adaptive control but uses methods for data-driven model adaptation



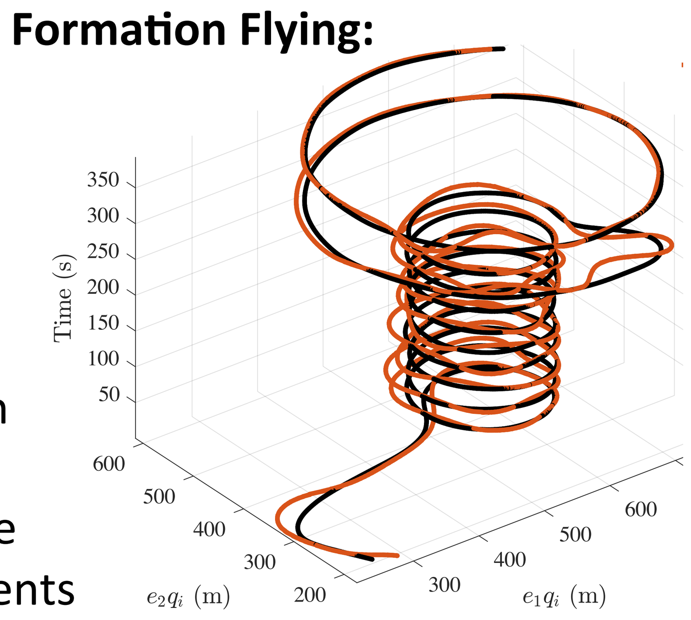
Results using RANS k–ω models are promising, but new high-speed high-fidelity turbulence models will be developed and its parameters will be adapted using DART

UAV-Bases Sensing: Measurement of potential temperature distribution using 3 UAVs. Results show increased complexity of the scalar distribution near the surface caused by topographical effects



Cyber-Feedback-Based Formation Flying: New formation flying methods, which take advantage of cyber feedback from DART-CFD, will be developed.

Preliminary results with new relative-to-leader formation algorithm are promising but experiments need to be extended to formations with more UAVs



Broader Impact: Society

DART flow-field estimation CPS has application to problems of noteworthy societal importance

Emergency Response: Predicting the dispersion of airborne contaminants (e.g., chemical, biological, radiological, nuclear) in real time is critical for safety of emergency responders and for response planning

- Fukushima Daiichi nuclear disaster and the Aliso Canyon natural gas leak are recent examples
- Other emergency response applications could include forest fires, oil spills, fracking accidents, and train derailments

Wind Energy and Aviation Safety: Predicting atmospheric flow at a wind farm or airport can help optimizing operations and safety

Broader Impact: Education and Outreach

Undergraduate Education: Many elements of this project (e.g., hardware assembly, flight tests) are excellent topics for undergraduate research. Investigators have track records of attracting female and minority undergraduate research students

Graduate Education: Project supports 4 doctoral students, and the problems in this project will be the focus of their dissertations

Adult Education: Project will provide extension educational materials to first responders and law enforcement through the UK's Cooperative Extension Service and the eXtension online portal

Broader Impact: Quantify Potential Impact

Full-Scale Cyber-Physical Demonstration: DART CPS will be validated in a full-scale field experiment. The goal is to provide real-time flow-field estimation capability. A key metric for DART CPS' potential real-world impact is real-time suitability (i.e., the ratio of computation time to simulation time)