Air Quality Plume Detection and Monitoring Using UAVs and Unmanned Rotorcraft

J.B. Kosmatka & Chad E. Foerster
Dept of Mechanical and Aerospace Engineering
University of California, San Diego

M. Lega
DiSAM – Dipartimento di Scienze per l’Ambiente
University of Naples PARTHENOEPE (Italy)

G. Persechino
CIRA – Italian Aerospace Research Center (Italy)

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Outline

• Introduction
• System Details
• Test Plan
• Results
• Conclusions
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Airborne Plumes

- **Plumes** are point source releases of pollutants that may include radioactive material, biological or chemical agents, and particulate matter.

- Possible massive **evacuations** to avoid contamination and health issues.

- A **fielded system** is needed that can identify, monitor and predict plume evolution:
  - Multi-scale for different plume types
  - Monitoring non-emergency activities

“UW Power plant malfunction sends black plume over Seattle”
KOMO News, December 2nd 2009

Roving Host Methodology

• **Stationary Sensor Network**
  – High cost of Installation
  – Best for dense urban environments
  – Suburban / wilderness require towers

• **Mobile UAV platform**
  – Low cost
  – Best for suburban / wilderness
  – FAA restrictions for populated areas

• **Proposed System**
  • Multiple autonomous vehicles with onboard path planning
  • Central command station to monitor the aircraft and relay information from the plume forecasting algorithm
  • A turn-key tailored system for first responders
UAV Selection

- Based upon probable threat scenarios, natural disasters or contaminant releases:
  - Plume growth, evolution, and duration
  - Sensor size/weight, onboard data reduction
  - Time/length scale of plume, sensor, aircraft
- Novel designs for dual purpose operations
  - Dart to plume, then slow loiter in plume

NextGen's shape-changing UAV morphs in flight

UCSD is a leader in novel UAV development

UCSD Jacbs Composite Aerospace Structures Laboratory

Los Alamos National Laboratory
Desired Platform Capabilities

- Determine loiter/cruise/dash speed, endurance, altitude, payloads
- Autopilot with failsafe modes that interacts with onboard microcomputer and a manned ground station
- Integrated sensors that provide input to onboard path planning algorithms
- Ground station that coordinates autonomous UAVs and relays navigation commands generated by the plume forecasting algorithm

Control Hierarchy:

- Manned Ground Station
- Plume Forecasting Algorithm
- Onboard Predictive Path Planning
- Onboard Adaptive Control Algorithm

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Plume Tracking Approach

- **Multi-UAV** tracking at different altitudes. Two different algorithms to determine plume shape, center, and motion

- **Quad-rotor** for low altitude source location. Sensitivity mapping to find plume source
## UCSD/LANL UAV Platform

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Empty Weight</td>
<td>5.97 kg</td>
</tr>
<tr>
<td>Flight Battery Weight</td>
<td>1.6 kg</td>
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<tr>
<td>Autopilot Weight</td>
<td>0.584 kg</td>
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<tr>
<td>Maximum Payload Weight</td>
<td>3.2 kg</td>
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<tr>
<td>Wing Surface Area</td>
<td>98.19 sq. dm</td>
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<tr>
<td>Wing Span</td>
<td>2.794 m</td>
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<tr>
<td>Cruise Speed</td>
<td>16-19 m/s</td>
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<tr>
<td>Maximum Speed</td>
<td>35 m/s</td>
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<tr>
<td>Stall Speed</td>
<td>9 m/s</td>
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<tr>
<td>Endurance</td>
<td>30-45 min at Sea Level</td>
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</table>
UCSD/LANL Quadcopter Platform

• **Specifications**
  – Max Endurance: 30 minutes
  – Max Payload Weight: 500 grams

• **Capabilities**
  – Fully integrated and tested autonomous and semi-autonomous modes including takeoff, landing, hover now, and waypoint navigation
  – Ability to interface with an auxiliary microprocessor board and modify path based on either source tracking or envelope mapping algorithms
Ground Station Software

• Provide interface between the autopilot and the operator, telemetry and sensor information

• Specialized GUI developed to log the position and sensor information for each aircraft

• A separate wireless network shares basic information between each UAV and relays commands to other out of range aircraft

• Adaptive control methods for source tracking and path planning using an onboard microcomputer. Provide navigation commands to the aircraft’s autopilot
Sensors

- CO$_2$, particulate, and chemical detection
- Final selection based LANL field restrictions
- Compact optical dust sensor was chosen which gave particulate density in mg/m$^3$
- Custom microprocessor board designed to accommodate future analog or digital sensors and interface with the autopilot
- Sensor location on the aircraft
  - minimize the response time
  - Evacuate any residual particulate matter in the sensor housing upon exiting the plume
Flight Operations at LANL Kelly Field

- Restricted airspace allowing for autonomous flight operations

- **Dedicated runway** for aircraft with landing gear and net capture setup for additional retrieval options
Plume Generation

- Off the shelf smoke grenades were used which emitted either Saf-Smoke or hexachloroethane (HC) smoke

- Single plume source could be moved around the flying field based on the weather conditions
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Wind Sensor Setup

- Three sensor locations:
  - One on flight-line at 1.5 m AGL
  - North and south of the runway at 9 m AGL

- Wind Sensor Specifications:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Units</th>
<th>Resolution</th>
<th>Accuracy</th>
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</thead>
<tbody>
<tr>
<td>Wind Speed</td>
<td>m/s</td>
<td>0.1</td>
<td>Larger of 3% of reading or least significant digit</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>º</td>
<td>1º</td>
<td>5º</td>
</tr>
</tbody>
</table>

- Test Flights: 25 to 75 m AGL collecting data
- Paths centered around wind sensor poles
- Data was collected using RC flights and autonomous UAV flights
Plume Release Studies

• Conducted in various weather conditions to ascertain the general progression of the plume at the flying field

• Plume source locations and grenade initiation timing were tailored for each flight to maximize the availability of the plume for sampling by the UAVs
Plume Releases with UAVs

- Multiple UAVs flown around the plume releases in a coordinated fashion to demonstrate the ability of the aircraft to identify and locate the plume with its onboard sensors

- **Low altitude passes** conducted to capture the highest concentration measurements

- Autonomous flights at higher altitudes performed at the aircraft’s cruise speed
Wind Estimation Performance

- **Noticeable lag** in wind estimation generated by the autopilot
- **Inability** to capture detailed wind changes close to the ground
- More robust methods are **needed** for estimating wind speeds

Estimation Results: First 500 seconds are in RC mode at altitudes below 50 m, from 500 to 1100 seconds it is in autonomous mode at 100 m altitude, transition back to RC mode after 1100 seconds
Particulate Sensor Readings

• Sensor saturation on almost every low altitude pass through the plume

• For each pass through the smoke the system logged three to four samples a second, a pass usually lasted one to two seconds

• Currently investigating slower vehicles and faster sensors to get more data within the plume.
3D graphs of plume passes

Successfully mapping plume definition
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Demonstrated Capabilities

• Autonomous aircraft operation with multiple onboard sensors and computer systems for adaptive plume identification.

• Coordinated multi-UAV flights for plume identification and tracking
Current Studies: Wind Estimation

- **Wireless ultrasonic sensors** tethered to weather balloons at 25 m intervals from 0 to 150 m to get a wind profile map.

- Multi-aircraft flights with individual aircraft tackling the wind estimation in certain altitude bands provide a wind profile estimate that can be compared to the wind sensors.

- Investigate preferred aircraft closed path definition for wind speed and direction.
Current Studies: Improve Mapping

- **Increase the sampling frequency** of the onboard sensors to provide a more precise mapping of the variations in particulate concentration.

- Use a **slower fixed wing UAV** platform to better match the release capabilities of the LANL flying field.

- **Validate** sensitivity search algorithm for locating plum source using the quad-rotor.
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