Toward Large Area 3D Trace Gas Concentration Mapping at Low Altitude Above Rugged Terrain

JACK ELSTON
It’s difficult to measure the impacts of elevated background levels of CO2 in the tropics.

Volcanoes in Costa Rica have been leaking CO2 into the overlying ecosystems similar to future atmospheric concentrations.

This provides a fortuitous natural experiment with which to test the ecosystem responses.

UAS flights in will measure CO2 and plant response around volcanoes in Costa Rica in order to understand the ecosystem response in the tropics, the lungs of the planet.
Issues: Environment

- Turrialba volcano
  - Significant gradient
  - Limited ingress locations
  - 3040 m (10,000 ft) AGL
  - Forested
- Vent
  - Located in valley that runs from summit
- Weather
  - Commonly overcast and windy
Issues: Guidance

- Current state of the art
  - Rough guidance, mostly by hand
  - Human-based sensor reactive flights
  - Limited by ceiling, endurance and payload size
  - UI not specifically designed for sampling
  - “Hacking” solutions from COTS systems
Issues: Payload

- Access to sensor required for 90 minute calibration
- Pump, tubing, filters and sensors weigh 2.2 kg (5 lbs)
- Sensor is fairly large
- 60+ minute flights to cover full area
### S2 SPECIFICATIONS

#### Mission Capabilities

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingress Protection (IP)</td>
<td>IP42</td>
</tr>
<tr>
<td>Payload Weight vs Launch</td>
<td>1.4 kg (3 lbs) hand launchable, 2.3 kg (5 lb) rail or car launch</td>
</tr>
<tr>
<td>Flight Ceiling</td>
<td>6000 m (20,000 ft)</td>
</tr>
<tr>
<td>Max Winds Endured</td>
<td>15 m/s (30 kts)</td>
</tr>
</tbody>
</table>

#### Flight Characteristic (6 kft density alt)

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight Speed</td>
<td>12 m/s (24 kts) stall, 18 m/s (35 kts) cruise</td>
</tr>
<tr>
<td>Flight Time</td>
<td>110 max, 90 min nominal</td>
</tr>
<tr>
<td>Range</td>
<td>110 km (60 nm) max, 92 km (50 nm) nominal</td>
</tr>
</tbody>
</table>

#### Vehicle Characteristic

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>5.2 kg (11.5 lbs) nominal, 6.6 kg (14.5 lbs) max</td>
</tr>
<tr>
<td>Wingspan</td>
<td>3.0 m (10.0 ft)</td>
</tr>
</tbody>
</table>

#### Payload Capabilities

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose Cone Dimensions</td>
<td>20.3 cm (8 in) diameter, 63.2 cm (24.9 in) length</td>
</tr>
<tr>
<td>Power available for payload</td>
<td>50 W total</td>
</tr>
<tr>
<td>Payload Weight</td>
<td>2.3 kg (5 lbs) max with rail launch</td>
</tr>
<tr>
<td>Geotagging Position Accuracy</td>
<td>Typically &lt; 4m in all directions</td>
</tr>
<tr>
<td>Downlink Data Rates</td>
<td>Serial Stream, 9500 bps</td>
</tr>
</tbody>
</table>
CO₂ Concentration [PPM]

Calibrated
Calibrated Abs

Results
Results

Google Earth
Results
Results
Actual vs Simulated Flight with New Algorithm
New Sampling Patterns

Terrain Mapping

Mapping Coverage

**ALTITUDE MODE**
- Terrain Following
- Fixed Altitude

**ALTITUDE REFERENCE**
- Fixed Height: 120 m
- Fixed GSD: 0.03 m

**LATERAL SEPARATION**
- Sensor Specific: SwiftTrainer - Sony A100
- Fixed Width: 120 m

**WAYPOINT ORDERING**
- Zamboni
- Sequential
- Iso-Contour

[Options: Cancel, Confirm]
New Sampling Patterns

Mapping Coverage

- **Altitude Mode**
  - Terrain Following
  - Fixed Altitude

- **Altitude Reference**
  - Above Sea Level: 3300 m
  - Above Your Location: 120 m
  - Volumetric

- **Volumetric Mapping**
  - Min. Altitude: 3300 m
  - Max. Altitude: 3500 m
  - Spacing: 100 m
  - Start at Min. Altitude
  - Start at Max. Altitude

- **Lateral Separation**
  - Sensor Specific: SwiftTrainer - Sony A100
  - Fixed Width: 120 m

Top View

Side View

CARTAGO PROVINCE

Volcan Turrialba

Parque Nacional Volcán Turrialba
New Sampling Patterns

- Simple double click back on itself makes this plan.
- New algorithm automatically tracks this.
Enter Orbit Radius

Orbit Radius: 85.5 m

Helix

HELIX PARAMETERS

- Terrain Following
- Above Sea Level
- Above Your Location

Min. Altitude: 3300.0 m
Max. Altitude: 4125.0 m

Path Angle: 5°
Rate: 1 m/s
Start at Bottom
Start at Top
Continuous

Confirm
Terrain Aware Patterns
Terrain Aware Patterns
Additional Sensing

Figure 13: Onboard view of 6 different avoidance maneuvers. The red voxels show detected obstacles and the green squares show the planned trajectory as it is being executed. The top left view shows an artificial obstacle and the remaining 5 are trees.