VOLCANO CO-ROBOT ADAPTIVE NATURAL ALGORITHMS (VOLCAN)

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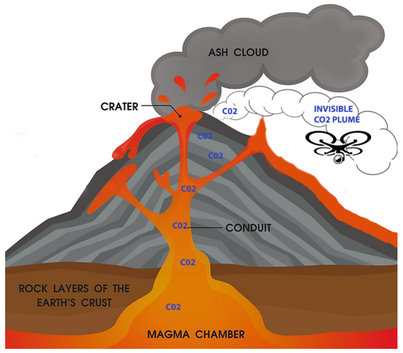
Challenge: Using Co-Robotics to Understand Volcanoes

Measure invisible CO_2 concentrations in plumes to predict eruptions & inform climate models



•Use UAS teams to identify plumes fast, •Estimate plume flux, •Find maximum CO2 source

Optimally Mapping Plume

We developed an efficient plume mapping algorithm, the *Sketch* algorithm,and prove that the error is bounded by 8 $\times$ the square root of the minimum change in movement. Moreover, the robots travel a total distance and rotate a total amount that are both asymptotically optimal.

Objective: Assuming a minimum movement of length λ *or,* turning at least λ radians, we want to estimate the boundary region of the plume with only local information gathered by the drone sensor i.e. gradient at the boundary crossing-point.

Results: For any positive $\lambda < 1/2^6$, the sketch algorithm uses 2 robots to compute an ϵ-sketch (an approximated polygon of the boundary such that every point of the plume boundary stays within ϵ distance of the output polygon) of the boundary, for $\epsilon = 8\sqrt{\lambda}$.

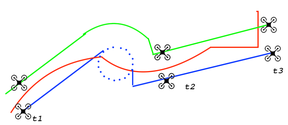
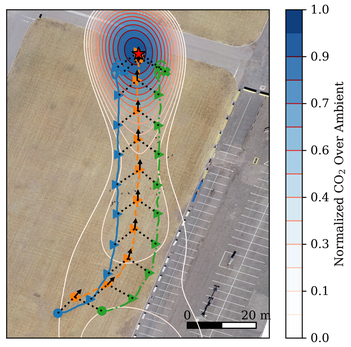


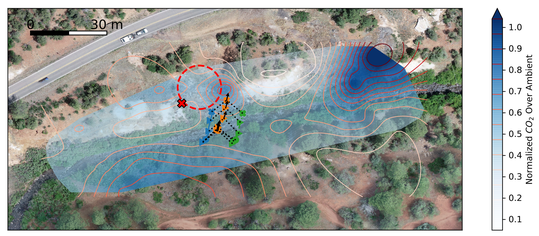
Figure 1: Illustration of the drones over times t_1, t_2, t_3. Red curve indicates the shape boundary; blue and green curves indicate the trajectory of the drones. Dotted blue line indicates the change in direction and step length required to ensure that the drones will again sandwich the boundary.

Flock Search for Maximum Concentration

Solution: Collaborative capabilities allow multiple UAVs to share data in real-time, acting as one re-configurable scientific instrument. Algorithms are tested in simulation, evaluated in local field sites, and finally leveraged to gather data on expedition at active volcano sites.



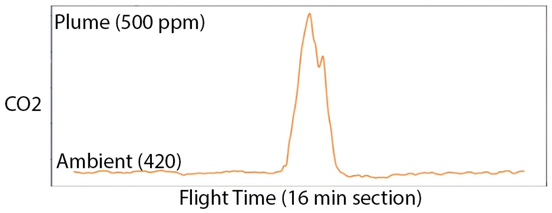
Iso-Concentration Maps



Valles Caldera supervolcano field tests, NM identified multiple CO_2 hot-spots corresponding to ground sources. CO_2 iso-concentration map generated by DragonFlies.

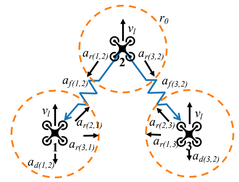
Field Tests

We tested the dragonfly platform in several locations: Valles Caldrea Volcano, (USA, 2021), Rooselvelt Thermal Springs (USA, 2021), Katla (Iceland, 2022), and during the catastrophic eruption on La Palma island (Spain) in November of 2021. The drones were able to located the CO_2 plume and retrieve a sample of magmatic gas.



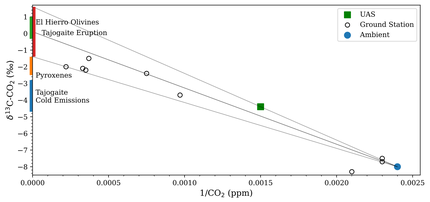
The Dragonflies sampled CO_2 (ppm) from the plume emanating from the active La Palma. Multiple missions collected direct plume CO_2 samples. The elevated CO_2 of the plume is clearly visible against ambient CO_2. Carbon isotope analyses were done on the collected CO_2 gases in La Palma which showed that the gases have correlated to known deep-sea sources originating from deep within the earth's mantle. This may explain the violence and duration of the eruption.

Dragonfly Robots



Custom built robotic flocking platform running ROS and capable of on-board CO_2 concentration analysis and multi-agent coordination.

Isotopes Characterise Eruptions



- Currently practices with CO_2 measurements conducted by ground field-crews are dangerous..
- Satellite cannot measure CO2 so CO_2 is estimated from SO_2 observations. Drones allow direct measurements.
- Sampling in-plume gases allows for carbon isotope analyses which help forecast the course of eruptions.

Scientific and Broader Impacts

CoRobot Impact: Advance understanding of autonomous adaptive co-robot algorithms & scientist in-the-loop environmental sensing in harsh environments. The technology has now been proven at multiple active volcanoes.

Broader Scientific Impacts: Help geologists predict volcanic eruptions with potential to save thousands of lives. Theory proofs apply to all 2D shapes which advances computational geometry.

Publications

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- Z. Miao, H. Zhong, J. Lin, Y. Wang and R. Fierro, "Geometric Formation Tracking of Quadrotor UAVs Using Pose-Only Measurements," IEEE Transactions on Circuits and Systems II: Express Briefs, vol. 69, no. 3, pp. 1159-1163.
- G. A. Cardona, D. S. D'Antonio, R. Fierro, and D. Saldaña, "Adaptive Control for Cooperative Aerial Transportation Using Catenary Robots," IEEE Aerial Robotic Systems Physically Interacting with the Environment (AIRPHARO), Croatia, Oct. 4-5, 2021, pp. 1-8.
- Ericksen, John, Abhinav Aggarwal, G Matthew Fricke, and Melanie E Moses. "LOCUS: A Multi-Robot Loss-Tolerant Algorithm for Surveying Volcanic Plumes". In: IEEE Robotics and Computing Conference (IRC). IEEE, 2020.