Subterranean Exploration Using a Train of Autonomous Vehicles

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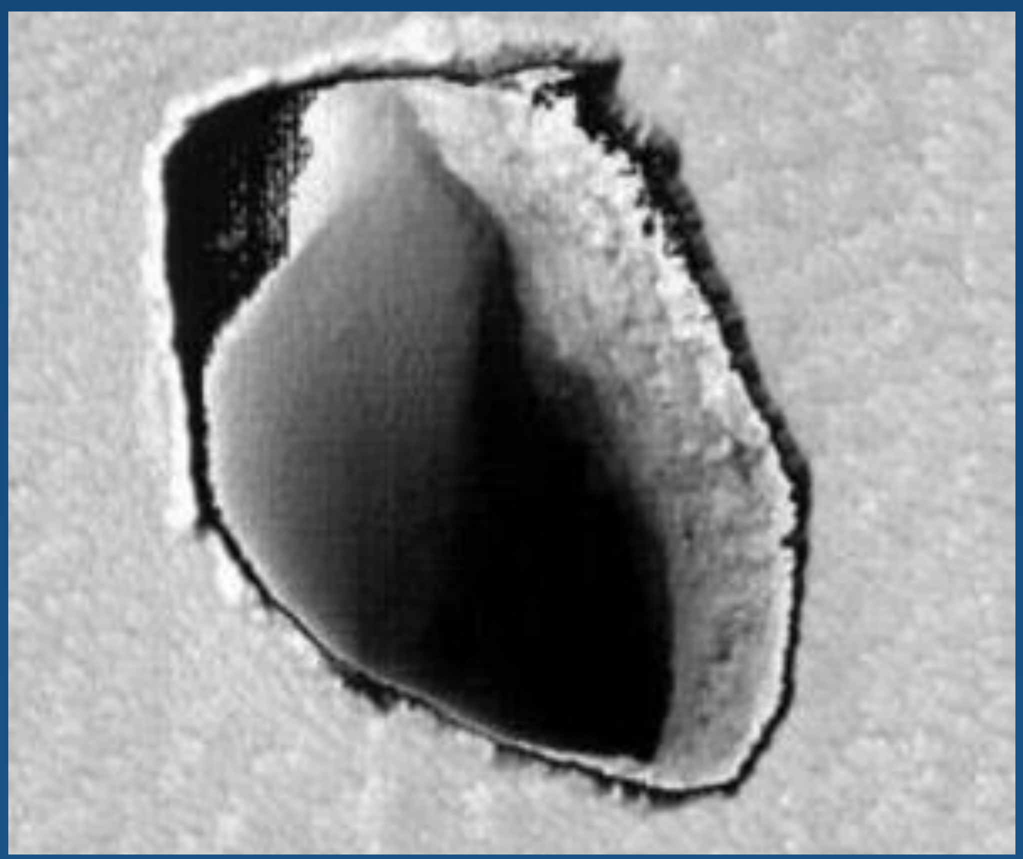
Introduction

Caves and lava tubes provide a unique environment for preserving microbial life. Orbiters have discovered pits on the surface of Mars that resemble caves or lava tubes. By analogy with Earth, caves on Mars may contain signatures of past microbial life and be valuable resources for study. This project presents a conceptual design for an autonomous vehicles system for the exploration of subterranean GPS-denied environments.

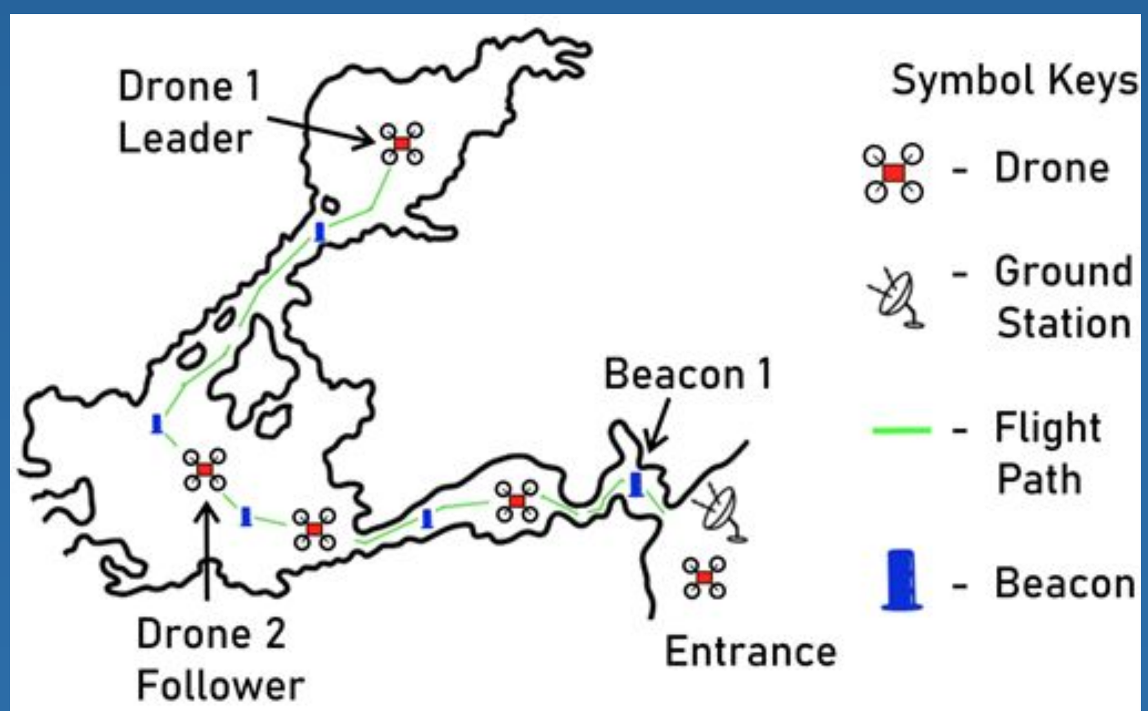


Pit Located in Tractus Fossae on Mars (Credit: NASA/JPL/University of Arizona).

Concept of Operations

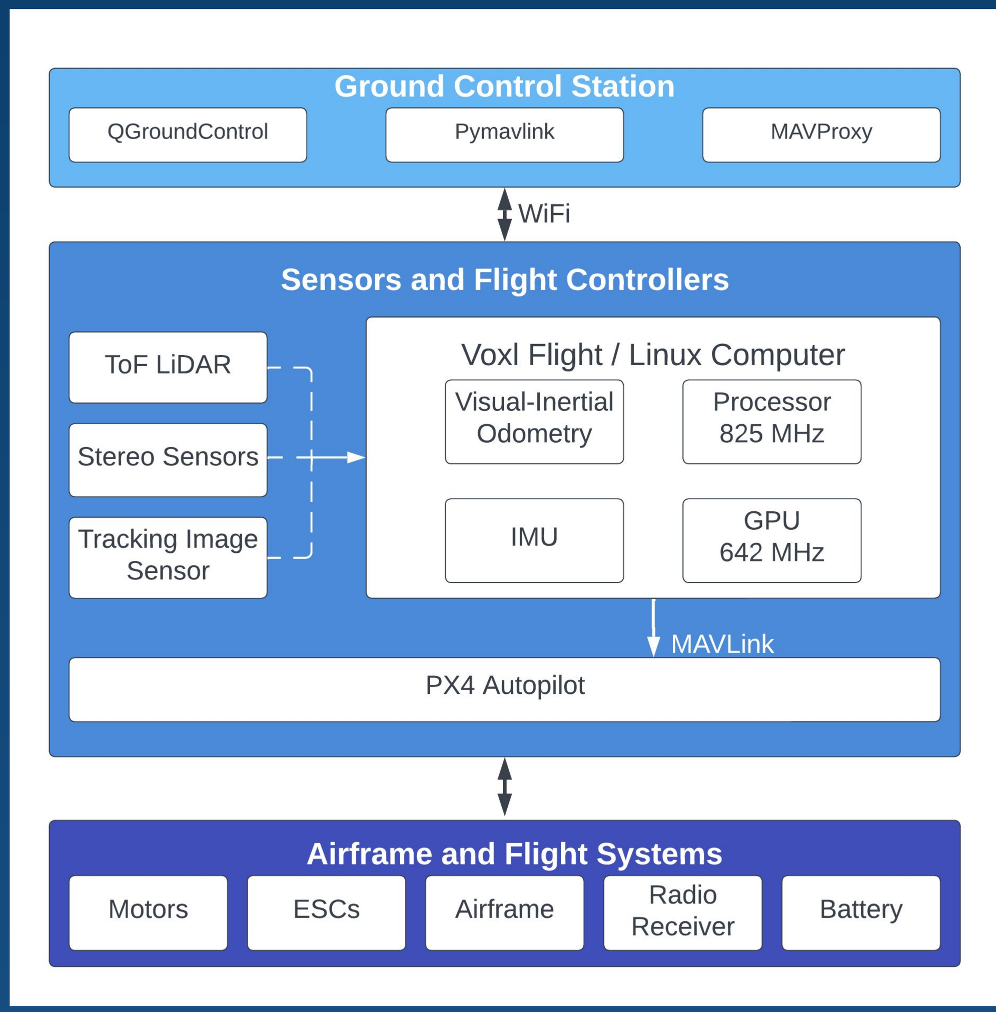
The proposed system is comprised of a leader drone, which enters the cave first and explores new passages, and a train of follower drones that follow in the leader's footsteps. Telemetry beacons are dropped to maintain RF signals around sharp corners. The system has the following tasks:

- Navigate autonomously without GPS
- Maintain connection to ground station throughout flight
- Collect data on cave geometry and flight path



Train of drones in a leader-follower configuration.

Facility and Setup



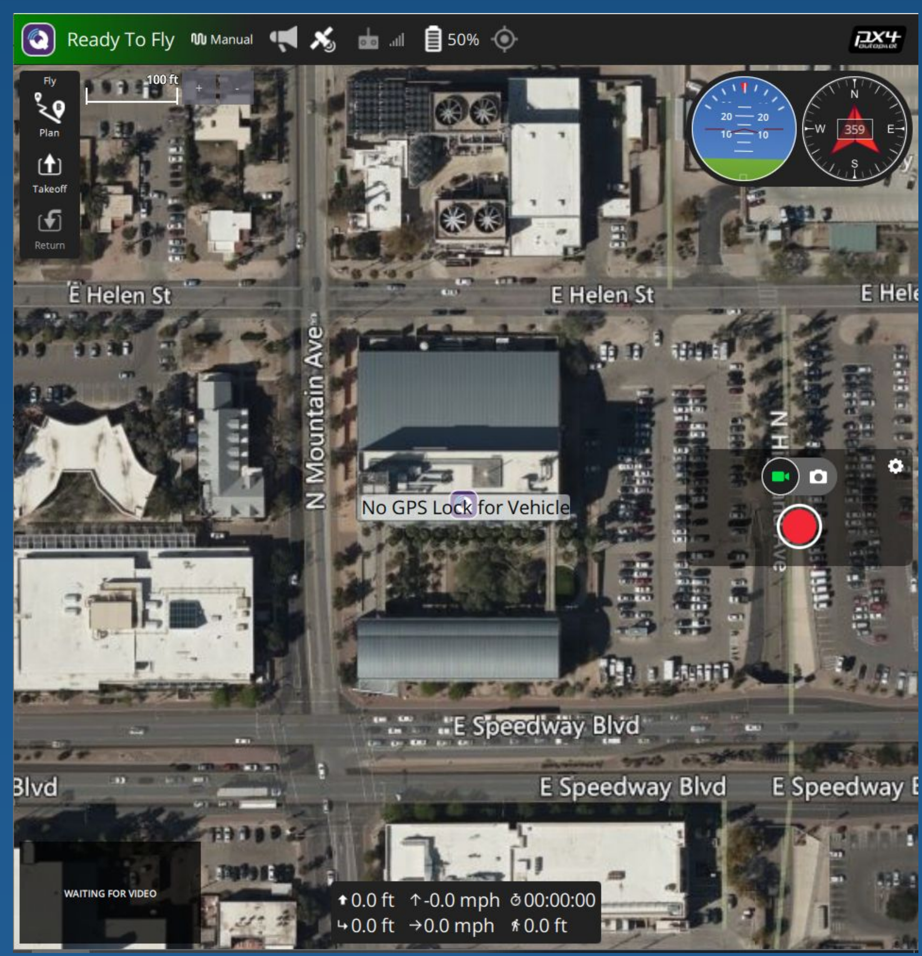
System diagram of each autonomous vehicle. A single ground station is shared among all the vehicles.

A 5 by 5 by 3 meter enclosure is used to test drones. The safety net catches drones in the event that control is lost.

Drone safety net and flight testing area.

Development drones utilize a simultaneous localization and mapping (SLAM) algorithm, time of flight (ToF) sensor, stereo image sensors, and tracking image sensors to facilitate navigation in indoor environments.

ModalAI Seeker Drone utilized for testing and development.



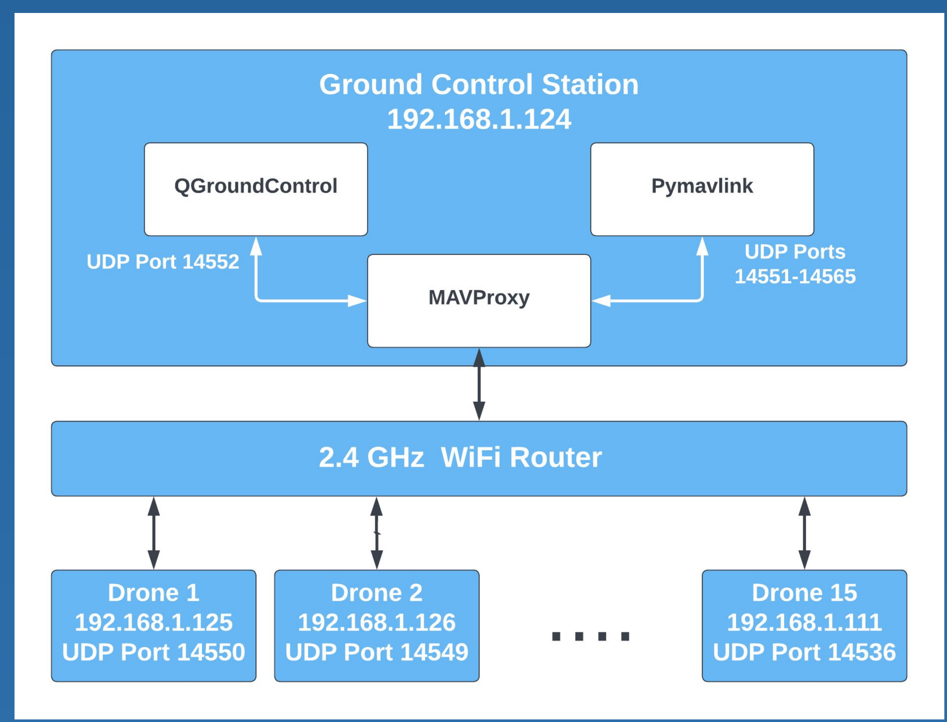
View from the ground station side in QGroundControl.

Methods

Visual-Inertial Odometry (VIO): The pose and velocity of the drone are estimated by using the output of the ToF sensor, stereo image sensors, tracking image sensors, and IMUs. The VIO data is used to direct the drones to specific coordinates.

Drone camera output with VIO data shown.

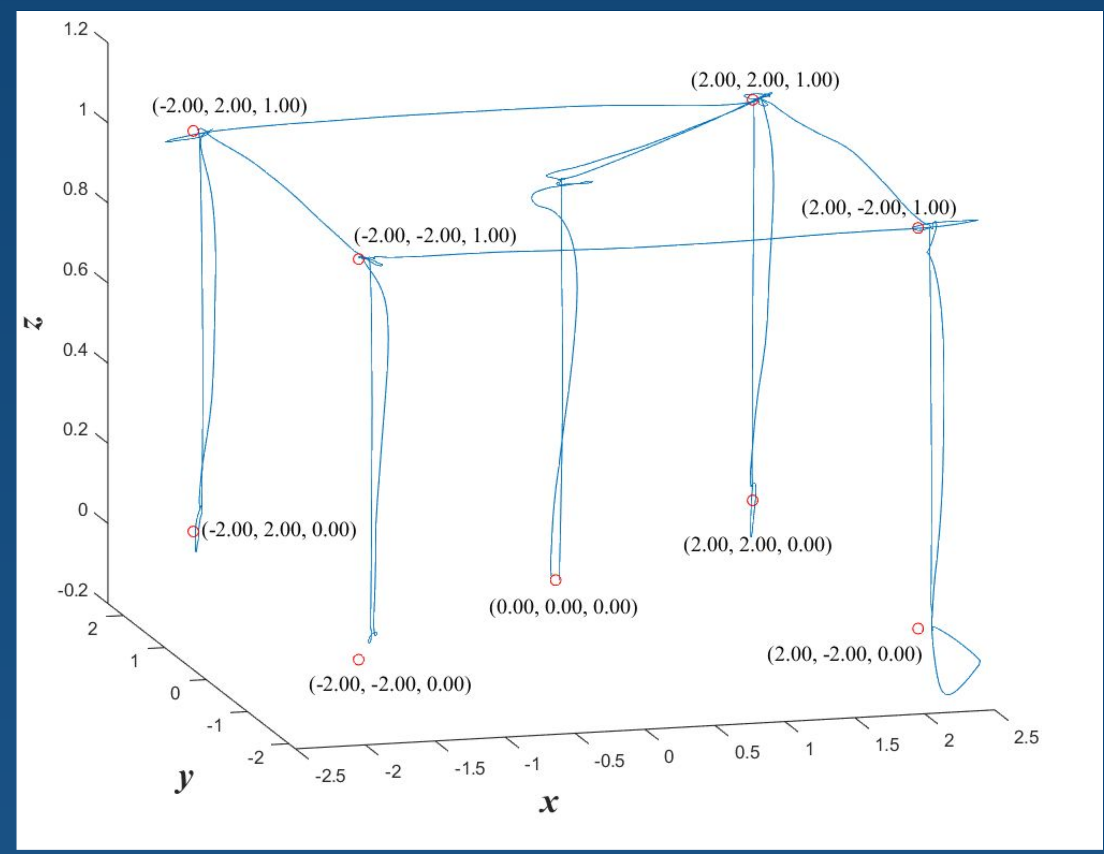
All of the drones in the train connect to a common WiFi network. Then, telemetry traffic can be routed to and from the ground station, allowing drones to follow the path set by the leader drone.



Telemetry routing diagram.

Results

Through VIO localization, the development drones are successfully flown in a pattern to demonstrate navigational ability. A drone takes off from the center of a 4 by 4 meter box, proceeds to one corner, and then visits each corner of the box, landing and taking off again at each stop. After the box is navigated, the drone lands in the center where it took off from.



Recorded local position of the drone during a test flight.

Through telemetry routing, multiple drones are able to be commanded from a single ground station.

Multiple drones being controlled simultaneously.

Discussion

Discrepancies between the target coordinates (red) and the estimated flight path (blue) may be attributed to imperfect PID calibration. Inaccuracies in the altitude estimation when the drone was landed on the ground may have been caused by slight errors in the VIO localization.

Implementing the leader-follower algorithm to create a train orientation of drones is the next step in the project.