Subterranean Exploration Using a Train of Autonomous Vehicles

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ABSTRACT

The work presents a conceptual design of a system of drones for the exploration of caves and lava tubes. Caves and lava tubes provide a unique environment for preserving microbial life. Orbiters have discovered dark 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 become valuable resources of lava-flow thermodynamics and hydrodynamics gravity. The objective of the present project is the development of the autonomous vehicles system for the exploration of caves and lava tubes featuring environments analogous to expected on other planets, e.g., Mars.

Previous publications have outlined localization and mapping methods to undertake complex and GPS-denied navigation inside terrestrial cave environments. LiDAR and onboard cameras are often used in an optical flow arrangement for local position estimation. Similarly, this conceptual system employs 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.

However, the conceptual system expands upon previous work by proposing a swarm of drones and beacons communicating through a ground station. Multiple drones explore in a train configuration, deploying WiFi beacons along the way to provide continuous communication between the drones and ground station, even around sharp corners. The detection of the cave entrance and finding the pathway in an unknown and inaccessible environment is based on an artificial intelligence algorithm integrated into specialized flight controller software.

The experimental program aiming to validate the developed system is underway. GPS-denied navigation and visual-inertial odometry (VIO) based localization are being tested in laboratory conditions while the machine learning based feature recognition is being tested in outdoor caves. Recent development and testing centers on a custom ground control algorithm that harnesses MAVLink communication to provide fully autonomous control for the drones in the GPS-denied environment.

The preliminary results of this study demonstrate the feasibility of autonomous drone exploration in GPS-denied environments and provide a running start for the leader-follower arrangement proposed to control multiple drones in a train configuration.