ROVERS AND LASERS: THE AUTONOMOUS, NON-DESTRUCTIVE SEARCH FOR LIFE IN LAVA TUBES.

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Introduction: Life, both microbial and human, requires protection from ionizing radiation. On the Moon and Mars, sites devoid of a protective atmosphere, effective shielding from ionizing radiation can be provided by 3 meters of ice, rock, or soil [1]. Lava tubes offer such protection, have been identified on both the Moon and Mars [2], and are accessible via skylight entry points for robotic and human exploration [3; 4]. These tube systems have been proposed as both potential habitats for extant or ancient life [5], and also as optimal sites for human colonization [6].

Unfortunately, robotic exploration of lava tubes on a distant moon or planet is problematic. The rich mineral composition of lava tube walls that provides effective shielding from ionizing radiation, also interferes with the electromagnetic radiation necessary for communication with Mission Control.

Approach: We report here on work conducted at Harvey Mudd College by undergraduate students to build the optical science probes and the cooperative, autonomous rovers necessary to map and search for life in the radiation-shielded lava tubes of Mars. Groups of autonomous robots are deployed at a lava tube entrance to navigate the tubes, produced detailed maps of the tubes, and investigate scientific targets of opportunity. The robots are equipped with imagers and spectrometers to characterize tube geochemistry and will utilize intelligent pattern recognition to identify optical biosignatures of putative microbial life. The imaging and spectral probes are non-contact and non-destructive. Exploration and mapping is accomplished with autonomous navigation without communication with mission control.

Navigation and Localization. The system currently utilizes modified DrRobot Jaguar Lite rovers. Each rover uses odometry corrected with a feature-based particle filter to localize itself in the rugged lava tube site. It is capable of accurately marking and later autonomously returning to sites of scientific interest.

Science Package. Rovers are currently fitted with reflectance and fluorescence imaging and spectroscopy systems. Development of a laboratory Raman spectrometer is currently underway and construction of a field Raman system will begin this summer.

Mars Analog Field Tests: Located in the Mojave desert within a two hour drive of the HMC campus, the Pisgah volcanic field is an accessible area of Holocene basaltic lava flows providing multiple lunar and Mars analog lava tube test sites. Fig. 1 depicts a rover with science package in the midst of a Mars analog surface region of the crater.

Figure 1. An autonomous rover amidst the ash and rocks of the Pisgah lava field.

For rapid mapping of a new site, rovers can operate more easily using only internal lights, camera, and laser mapping hardware and software. Fig. 2 depicts a rover entering a lava tube for an initial mapping run.

Figure 2. A rover approaches a lava tube entrance for a mapping run.

A real time navigation example is depicted in Fig. 3. During field trials students monitor rover mapping progress using a laptop and wireless communication protocol. The current graphical user interface (GUI) provides real time display of mapping progress (Fig. 3A). The tube walls in the current map (grey) are indicated in the top down view in the left pane. Circles indicate desired waypoints to track. Green lines indicate current laser range measurements, and colored "particles" indicate state estimates of the robot's position with respect to the map. The blue particle is the weighted average of all particle positions. The lava tube walls directly in front of the rover appear inf Fig. 3B. Fig. 3C depicts an example rover path (in blue) from a field trial in which the rover autonomously navigated down the lava tube.

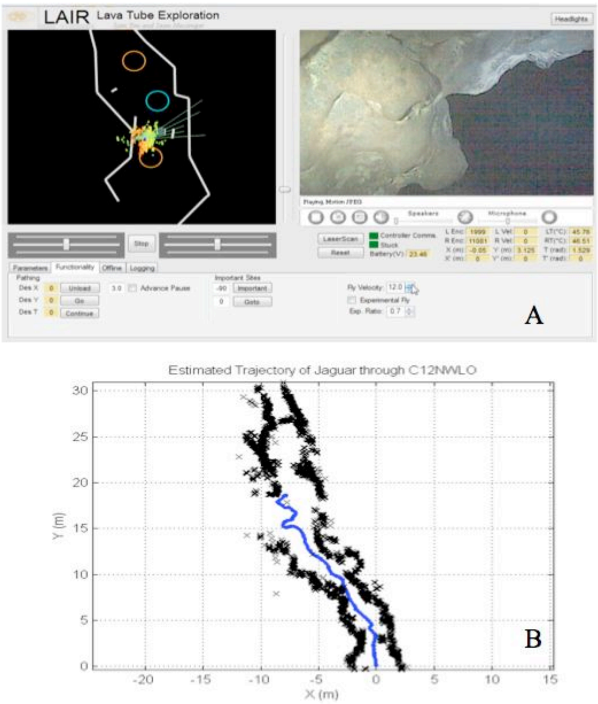

Figure 3. The GUI interface with (A) the real-time display of the rover mapping, (B) the view of the lava tube using the rover's internal imaging system, and (C) a completed map of a lava tube.

Fig. 4 depicts a rover (A) carrying a science packae (B) sitting on the sandy floor (C) of a lava tube scanning the walls (D) for a target of interest (E). The science module captures a reflectance image (F), a fluorescence image (G), and (H) the fluorescence spectrum (*Ex=405 nm*) of the target. Investigators monitor the rover's progress using a laptop computer GUI that displays the rover's position with respect to the map (I) produced during the laser mapping run. The rover's camera feed (J) provides context for the robot.

The emission peaks for the target at 466.6, 486.6, 507.8, 525.6, 544.4, and 569.3 nm are most similar to carbonate species such as agricolaite. The rover has used data generated during an earlier autonomous mapping run to return to this previously tagged target of interest.

Future Work: This summer work on our rovers will focus on the replacement of 2-D mapping techniques with autonomous 3-D mapping capability. Work

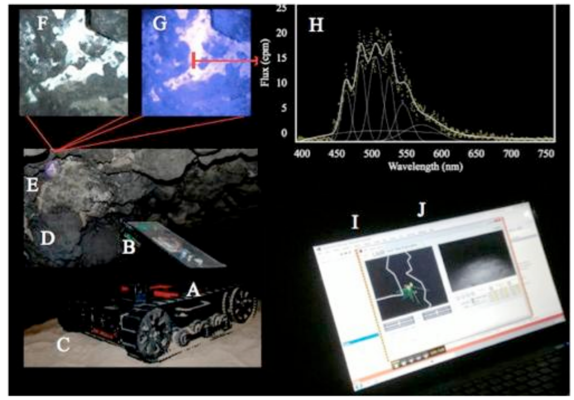

Figure 4. Rover (A) with science package (B) sits on the sandy lava tube floor (C) searching basalt walls (D) for targets of opportunity (E). Reflectance (F) and fluorescence (G) imaging and the fluorescence spectrum (H; Ex=405 nm) identify the target as a carbonate. The map (I) and the view using the rover headlights and internal camera can be seen (J) in the screen shot of the laptop used to monitor the exploration of the tube.

on the science package will concentrate on design, development and testing of a field-capable Raman system and merger of that system with the rover platform. For further information see

http://newwww.hmc.edu/lair/projects.html

or

http://www.kinohi.org/life-in-caves-lava-tubes

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