

Underground Resource Prospecting Using a Semi-Autonomous, Multi-Instrumented Robot. John M Meyer¹, Dr. Elizabeth A. Holley², and Dr. John Steele³, ¹PhD. Student, Mining Engineering Department, Colorado School of Mines, 1600 Illinois Street, Golden, Colorado, 80401, johmeyer@mymail.mines.edu, ²Assistant Professor, Mining Engineering Department, Colorado School of Mines, 1600 Illinois Street, Golden, Colorado, 80401, eholley@mines.edu, ³Associate Professor, Mechanical Engineering Department, Colorado School of Mines, Brown Hall W350 1610 Illinois Street, Golden, Colorado, 80401, jsteele@mines.edu.

In-situ resource utilization (ISRU) has been identified as a strategy that will lower the launch mass of human exploration missions and significantly reduce the cost and risk of human exploration. The first steps in creating a complete ISRU capability, as described in NASA Technology Area Breakdown Structure (TABs) 7.1.1.[1], 'Destination Reconnaissance, Prospecting, and Mapping, comprise destination reconnaissance, resource prospecting, and resource mapping[1]. Any atmosphere or environment of an extraterrestrial body, including the regolith, may be a local resource for useful products. Extraterrestrial caves, especially lava tubes, have been identified as prime targets in the exploration for exploitable in-situ resources as well as signs of life. Caves on Mars are believed to contain resources such as water ice, methane hydrates, carbon dioxide hydrates, hydrothermally altered clays, and metal salts[2, 3].

Water is a prime candidate for ISRU, as it is a critical life support consumable and a potential raw material for oxygen and hydrogen production[3]. Martian caves may be viable water sources, containing significant quantities of ice [4]. Methane is a potential propellant option that could be produced by ISRU. Methane may also be used for energy production, with the added benefit of producing water and CO₂ as by-products. Gas hydrates sequester vast amounts of methane on Earth in marine sediments and permafrost regions [5]. Given the current average surface temperatures and pressures on Mars, gas hydrate should be stable in caves at a depth of ~ 15 m. [3]. Evidence for methane outgassing could be accomplished by robotic cave exploration. Ancient hydrothermal environments are thought to be excellent targets in the search for early life [6], and hydrothermally altered clays will act to preserve organic matter [7]. Clays appear to be restricted to Noachian aged (4.1-3.7 billion years ago) terrains. Multiple data sets obtained over the last decades show that frozen, arid conditions have existed on the surface of Mars since the early-Noachian period suggesting that the majority of aqueous alteration on Mars likely occurred in the sub-surface through interactions with heated groundwaters[7]. Caves on Mars would be highly prospective areas to search for evidence of a wetter, warmer Mars.

Current Mars orbiting systems do not provide information concerning underground voids nor the spatial resolution necessary for detailed local scale prospecting [7]. A ground-based multi-instrumented robot operating under supervisory control would be capable of collecting data required to map the water, methane, carbon dioxide, lithology, mineralogy, and clay species of Martian caves and conduct in-situ characterization of surface and underground geometry and geology. A robot equipped with these capabilities is currently under development and testing at Colorado School of Mines. The robot will be capable of operating on the surface or underground; however it is the robot's ability to perform these tasks in an underground environment, especially within caves, which will be the focus of this presentation.

The robot currently comprises a mobile platform equipped with a light detecting and ranging (LiDAR) instrument and stereo camera. A hyperspectral imaging system will be added in subsequent phases of the research.

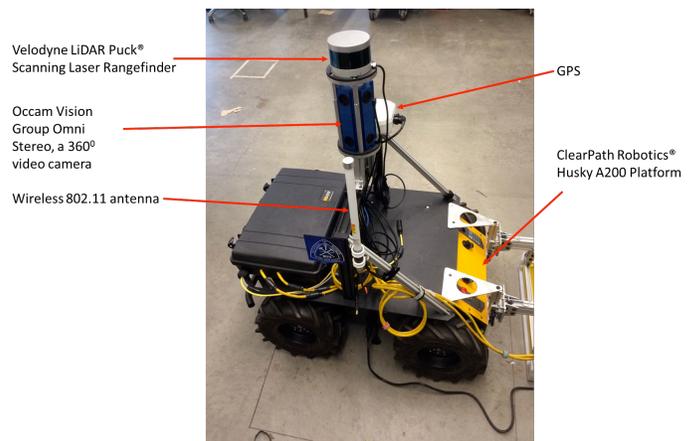


Figure 1 GeoBot, a robot comprising a mobile platform, LiDAR unit, stereoscopic video camera, GPS unit, and wireless communications equipment that is available at Colorado School of Mines for proof of concept testing and research.

The LiDAR collects point data that can be used in real time to give the robot self-sensing and self-perception of the environment and allow it to navigate within the void. The LiDAR point cloud data can be uploaded to

a server for remote processing to generate a digital map of the cave for future reference.

In keeping with the natural progression and evolution of control that has occurred in extraterrestrial rovers, and as detailed in TABS 4.2.6.4 [1], the robot will be given task line commands which it will then execute. Simultaneous localization and mapping (SLAM) algorithms installed as Robotic Operating Systems (ROS) nodes onboard the robot will enable the robot to enter the void, map the geometry and geology of the void, and return to the void portal in order to upload the data collected within the void.

The hyperspectral imaging system will collect data that will be uploaded to a server and overlain on the digital map to create a mineralogy map of the cave. Hyperspectral remote sensing's ability to differentiate the spectral variations between rock types gives it a distinct advantage over other remote sensing techniques when used to map surface lithology [8]. Liquid and solid water have unique and readily identifiable spectra in several bands between 667 and 2000 nm [9]. Hyperspectral imaging also allows for the identification of methane and carbon dioxide [3], the 770 nm band being highly sensitive to methane [10]. Hyperspectral instruments are able to identify minerals and differentiate between hydrothermally altered clays [8] such as smectite, kaolinite, and vermiculite. The ability to map the distribution and mineralogy of various clay species may aid in the exploration for ancient life forms.

A robot capable of entering the potentially resource rich environment of caves on Mars, mapping the geometry and geology of the caves and returning to the surface, without receiving direct guidance from human operators, would be a first step in in-situ resource utilization. The robot described in this presentation, equipped with a LiDAR and hyperspectral camera, will enable an evaluation as the feasibility of collecting and integrating disparate data sets and the usefulness of the integrated data set in characterizing and mapping the geometry and geology of caves. The methodologies developed will also be applicable on Earth, especially in the mining and underground construction industries.

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