Mobile LiDAR as a Tool for Terrestrial and Planetary Cave Exploration and Mapping

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Introduction: The Kinematic Navigation and Cartography Knapsack (KNaCK) team at NASA's Marshall Space Flight Center in Huntsville, Alabama is developing tools that enable ultra-high resolution terrain mapping and navigation using mobile LiDAR (Light Detection and Ranging) and SLAM (Simultaneous Localization and Mapping) algorithms in fully GPS-denied and unilluminated environments [1,2]. The backpack mounted LiDAR instrument under development by our team demonstrates the potential of mobile SLAM LiDAR for use in challenging lunar and planetary surface environments as well as for lunar, planetary, and terrestrial cave exploration, study, and utilization.

Background: Lava tubes and subsurface voids are thought to exist on the Moon, Mars, and other planetary bodies. These environments interest the space community because they could provide shelter from radiation [3], access to water deposits, and a space for habitation, as well as hold information about the geology, volcanology, and evolution of the Moon, Mars, and other planetary bodies [4]. Mobile LiDAR systems hold promise as a tool for investigating caves on Earth and throughout the solar system due to their ease of use, ability to see beyond the cast of visible light, ability to operate without GPS, and their rapid survey potential. These systems capture 3D point clouds by fusing range data from a sensor with estimates of the instrument's position as it moves through the environment. A multitude of point clouds are matched together with a SLAM algorithm to produce a complete picture of the environment's topography.

Caves as Terrestrial Analogs: Terrestrial caves are valuable as analogs for both planetary caves and planetary surfaces. Planetary surfaces have rugged and irregular terrain, difficult illumination conditions, and no access to GPS. Lava tubes and subsurface voids on the Moon, Mars, and other planetary bodies present similar challenges. Terrestrial caves are excellent analogs for these conditions, providing an opportunity to refine technology for mobile mapping and navigation on other worlds while advancing the State of the Art for cave survey on Earth. Overburden above cave passages blocks both light and GPS signals. Highly irregular geometry challenges scan matching algorithms and frequent jostling of the instrument due to rugged and confined terrain interferes with dead reckoning based on inertial measurements. Many terrestrial caves have also been previously surveyed. This provides a ground truth that can be used to quantify system performance.

Field Work: The KNaCK instrument has been used to map two terrestrial caves: Lava River Cave (Fig. 1 and Fig. 2), a lava tube in the San Francisco Volcanic Field of northern Arizona, and Three Caves (Fig. 3), a quarry in Huntsville, Alabama. Data used to generate a map of Three Caves was collected in just 6.5min, capturing a substantial portion of the maze-like complex with only a short, 370m traverse. The data used to produce a map of Lava River Cave was collected in 44min over 1100m and records the morphology of the cave at cm-scale. These maps contain 18.4M and 44.8M points, respectively, after post-processing. The accuracy of the Lava River Cave map was compared to an existing survey produced by the Central Arizona Grotto in the 1980s. The LiDAR map is shown to be accurate at the local scale (Fig. 2) but shows considerable drift from the traditional survey at the global scale (Fig. 1).

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References: [1] Zanetti M. R. et al. (2022) LPSC LIII, Abstract #2660. [2] Miller K. A. et al. (2022) LPSC LIII, Abstract #2808. [3] Caffrey J. A. et al. (2023) IPCC IV, Radiation and Nuclear Technology in Planetary Cave Environments, https://ntrs.nasa.gov/citations/20230006716. [4] Wynne J. J. et al. (2022) *JGR Planets, 127*, e2022JE007194.

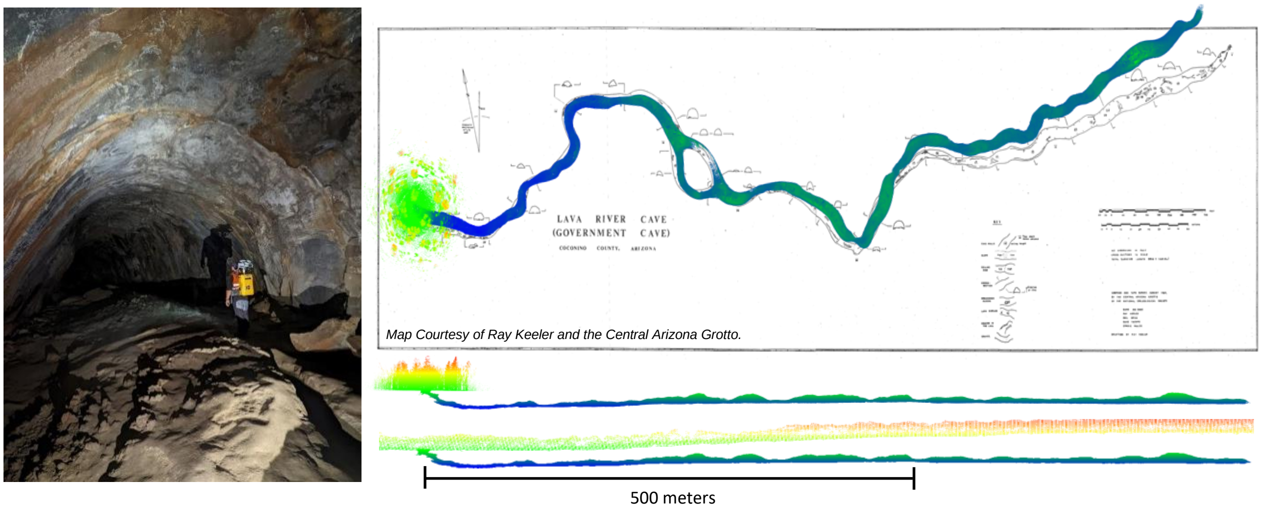

Figure 1. Lava River Cave: (left) scanning borehole passage, (top) LiDAR map overlaid with traditional cave map, (middle) profile view of LiDAR map, (bottom) NAIP Point Cloud DEM overlaid with LiDAR map.

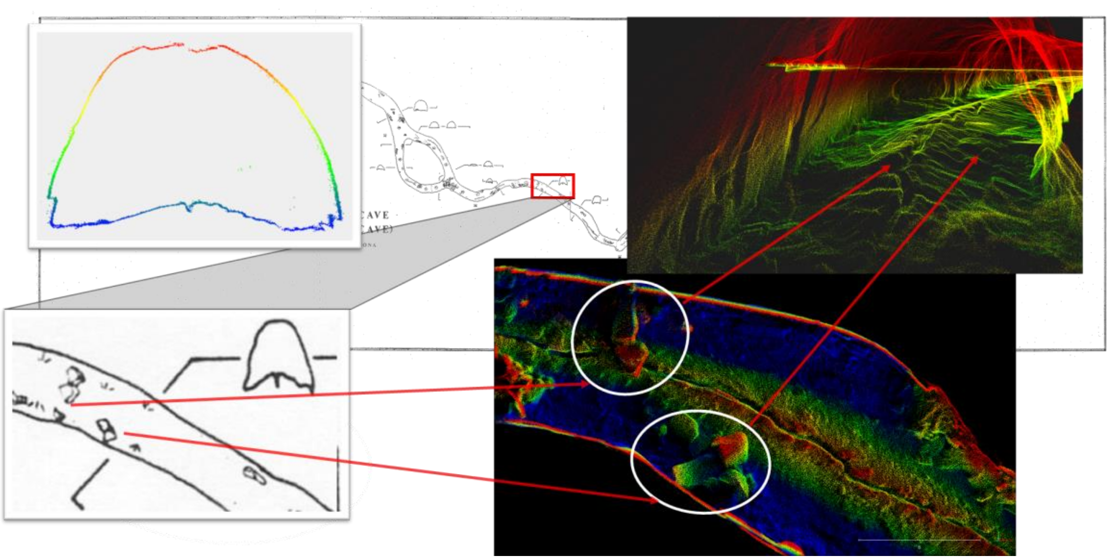

Figure 2: Fine Scale Features Captured at cm-scale Resolution

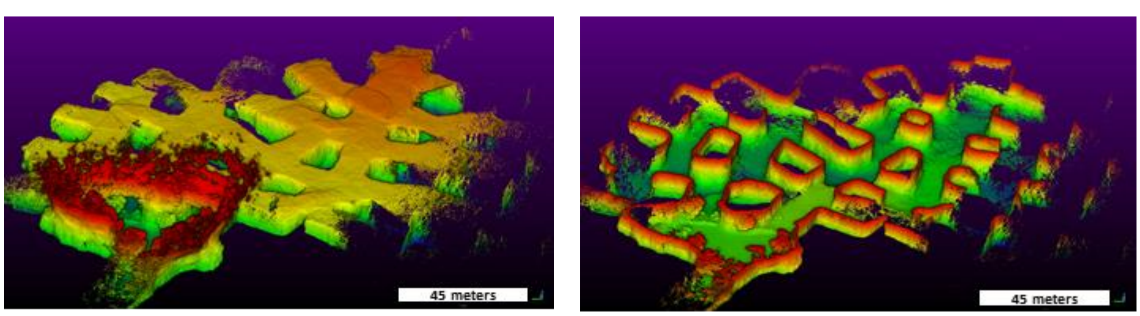

Figure 3: LiDAR Map of 3 Caves Quarry, Huntsville, AL, USA