TOPOGRAPHIC QUINTET: COMPARING FIVE METHODS FOR MEASURING ULTRA-HIGH RESOLUTION TOPOGRAPHY, P. Whelley[1,2], M. Zanetti[3], S. Scheidt[4], J. Richardson[2], Z. Morse[4], K. Miller[3], B. Steiner[3], P. M. Bremner[3], K. Young[2]. [1]University of Maryland, CP, Department of Astronomy – Center for Research and Exploration in Space Science &Technology II, College Park, MD 20742. [2]NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771, [3]Marshall Space Flight Center, Huntsville, AL, 35805; [4]Howard University, 2400 6th St NW, Washington, DC 20059. (patrick.l.whelley@nasa.gov; michael.r.zanetti@nasa.gov).

Introduction: We compare different methods for collecting ultra-high resolution topography data within an analog planetary, human landing site scale area. Our aim is to investigate the cost and benefits of different 3D terrain mapping techniques, their associated data collection methods, and how their different specifications (*e.g.,* range, spatial resolution, scanning-time, mobility, operating constraints, GPS-Denied operation, etc.) might be applied to landing-site characterization and mission operations. We compare 3D terrain data collected during a field campaign in November 2021 from an outcrop at Kilbourne Hole in southern New Mexico using different Light Detection and Ranging (LiDAR) sensors on the ground and stereo-derived 3D data from framing cameras mounted on small uncrewed aerial systems (sUAS).

Our foci for this experiment are ground-based, surveying, and autonomous vehicle-type 3D scanning sensors that might be used for planetary surface exploration from landed assets (*e.g*., lander, rover, astronaut-mounted sensors, decent imaging, hoppers, or drones). [*e.g.* 1] This test is not meant to benchmark these scanners against one another, nor provide a recommendation for a specific make or model. Rather, our goal is to quantify time, effort, resolution, and operational trade-offs that are important for selecting a topographic instrument/methodology for a given scope of terrain characterization. Our results indicate that each technique is capable of exceptional quality terrain characterization for planetary exploration and scientific inquiry, but we hypothesize the appropriate technique is highly dependent on the scope of operational specifications and science requirements.

Background and Methods: An outcrop ~10^3 m^2 was selected along the southeastern rim of Kilbourne Hole, a maar volcano rimmed by pyroclastic surge beds that exhibits stratigraphy, including cross-beds, that record the history of the eruption [2]. This outcrop was selected as it was accessible and easily traversable by both tripod and mobile scanning instruments [**Figure**]. It presents both macro- and micro- geologic topographic textures that were mapped using our instruments to allow for meaningful comparisons.

LiDAR determines the range from the sensor to objects by measuring the two-way travel time of sent and returned light pulses. Millions of range measurements are made to produce a point-cloud of 3D terrain coordinates.

Two different ground-based methods of LiDAR data collection were used: Tripod mounted LiDAR Scanning (TLS), and Kinematic LiDAR Scanning (KLS, or person-mounted mobile scanning) using the Kinematic Navigation and Cartography Knapsack (KNaCK; [3]). Four different LiDAR sensors were used (TLS: Riegl VZ-400, Leica BLK360; KLS: Ouster OS-1-64 and Aeva Aeries B1).

Topography generated from framing camera images is generated through multi-view stereophotogrammetry calculations using software, usually in post-processing. We used both a light and heavy sUAS camera configuration to acquire images: a >100 gram Hasselblad with a 1" CMOS sensor (20 MP) and a 700 gram Sony a7R IV with a full frame sensor (61 MP), respectively. Topography was derived using Agisoft Metashape Professional 1.6.4 software.

The fundamental product from the LiDAR and photogrammetry methods is a 3D point cloud that can be used as a model of the scanned surface, allowing topographic and morphometric measurements and characterization at a range of length scales, as small as a few millimeters depending on range distance.

Results: *Tripod mounted LiDAR scanning (TLS):* The outcrop was scanned using both a Leica BLK360, and Reigl VZ-400. Individual Reigl VZ-400 scan times range from ~5 min to >20 min, depending on chosen point spacing and other scan settings. Data from multiple scanning locations were "stitched" together to create a single 3D digital point cloud using postprocessing software, which use on a least-squares error minimization between points of overlapping point clouds. The Riegl scans consisted of nine 360° scans, six with 0.03° and three with 0.02° angular spacing. A total of >200 M data points were collected with point spacing as small as <1 mm, over an area of ~10^3 m^2. The summed time for all of the scans was 2.35 hours. Leica BLK360 data processing is underway. Data collection involved thirteen scan positions in 2.16 hours.

Kinematic LiDAR scanning (KLS): The KNaCK system produces 2 independent LiDAR maps, both with and without the aid of GPS for simultaneous localization and mapping (SLAM). Both GPS-enabled and GPS-denied maps were created from the same collected scan data and separately post-processed with KNaCK_SLAM_ROS2, a custom algorithm developed for our test-article instrument [4]. The user wore the KNaCK instrument as a backpack and traversed the field area in a pattern that minimized data shadows. For maximum point coverage and to aid loop-closure and SLAM algorithm processing, smooth arcs and circles were walked during the traverse. A total of ~84M points, with average point spacing of ~5 cm were captured in 9 minutes [**Table**].

sUAS Stereophotogrammetry: A lightweight sUAS configuration required 1.5 hours to collect 560 images that were used to create a topographic point cloud model of 800M points over an area of 4 × 10^6 m^2 which provides regional context. For comparison with TLS and KLS scans in a limited 10^3 m^2 area, the sUAS systems produced a point cloud of 11M points in 0.1 hours, as well as a color orthoimage mosaic and gridded DEM model a spatial resolutions of 2.4 cm/pixel.

Discussion: All methods were capable of producing high-quality 3D topographic data that could be used for morphometry, scientific context, terrain mapping, and navigation purposes. However, the TLS scans were the only methods that resolved the cross-bedded layering within the outcrop walls but took an order of magnitude more time to collect an order of magnitude more data. Within several meters of the collector, TLS observations produce the highest resolution data. The KLS system provided the quickest LiDAR maps of suitable quality for geologic context and navigation in the field and while ash layers are resolvable, cross-beds are not [**Figure**]. sUAS was faster still at collecting data of the target outcrop, and produced comparable effective resolution producs to KLS and using a passive sensor. Each method could be adapted, with minimal effert, to be effective in a GPS denied environment.

Overall, our experiment demonstrates the need to balance specific scientific observational requirements, operational and mission constraints, and technological capability. Careful consideration of requirements point density, area covered, target properties, precision, accuracy, and mobility should be made, and can be met through multiple methods.

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[3] Zanetti, M. et al., (2022) *LPSC LIII,* KNaCK project overview, *This meeting*. [4] Miller, K., et al., (2022) *LPSC LIII,* KNaCK_SLAM, *This meeting*

Table: Topographic methods comparisons for Kilbourne Hole quintet

Method		Data collection time (h)	Points in 10^3 m^2 (millions)	Data processing time (h)	Processed cloud data volume (MB)	Effect of denying GPS
Tripod-TLS	VZ-400	2.35	200	4	7500	Increase processing time by 25%
	Leica	2.16	*Processing underway*			
Backpack - KLS	Ouster	0.15	14	1.25	135	Increase processing time by 10% - 50% for SLAM
	Aeva	0.15	70	1.25	135	
sUAS		0.10	11	0.5	272	Increase data collection time

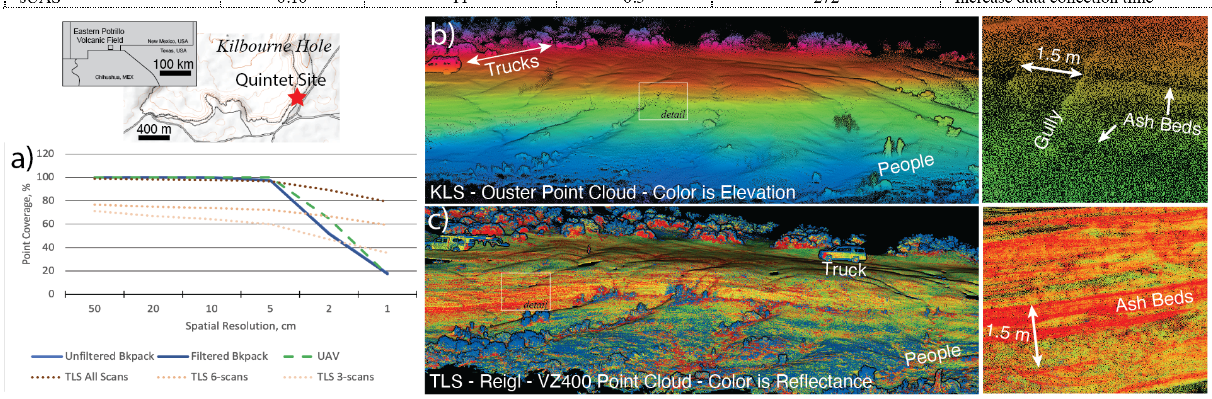

Figure: a) Comparison of data coverage (in %) at different spatial resolutions (pixel sizes of a DEM) for sUAS, TLS, and KLS (backpack). Multiple TLS scenrios are shown (dashed lines) as a proxy for time – 1/3 of the scans take ~1/3 of the time. b) An oblique view of the comparison outcrop in KLS – Ouster, Colorized by elevation. c) The same view in TLS Reigl VZ-400 (all scans), colorized by reflectance. Detailes of both are in the right column.