The Kinematic Navigation and Cartography Knapsack (KNaCK) LiDAR System: Overview and Applications.
M. Zanetti[1], B. Robinson[2], P. M. Bremner[1], B. De Leon Santiago[1], E. Hayward[1], K. Miller[1], B. Steiner[1], A. Draffen, J. Jetton[2], J. Walters[2]. [1]NASA Marshall Space Flight Center, Huntsville, AL 35805, [2]Torch Technologies, Huntsville, AL, 35802. (Michael.R.Zanetti@nasa.gov).

Introduction: Improved terrain characterization and navigation sensors and methods are needed to enhance crew safety, ISRU return, and scientific understanding of future landing sites. Specific to the Artemis Program and sustained exploration at the lunar South Pole, extreme low-angle solar illumination conditions pose significant challenges to existing photogrammetry-based robotic navigation. Additionally, a major challenge for navigation on the Moon and other planetary surfaces is the lack of Global Positioning and Navigation Systems (GPS or GNSS). Thus, there is a need for an alternative to image-based navigation that allow for precise and accurate mapping in GPS-denied environments on any planetary body [1]. Here, we describe the Kinematic Navigation and Cartography Knapsack (KNaCK) LiDAR system; a backpack-mounted, mobile navigation and terrain mapping system that uses a *velocity-sensing* coherent light detection and ranging (LiDAR) system based on a frequency modulated continuous wave (FMCW) technique, contains minimal moving parts, and employs sophisticated positioning algorithms. During a traverse, this instrument emits light pulses to continually scan a scene to build a three-dimensional point cloud representation of topography. A measure of the Doppler-velocity at each of millions of range points sampled per second allows for a 6 degree of freedom (6-DoF) estimate of the sensor's position and the development of novel position-from-velocity mapping and positioning algorithms for loop-closure in GPS-denied environments.

Motivation: The development of self-driving automobiles on Earth can be leveraged to advance exploration capabilities on planetary surfaces. LiDAR is an active source illumination method that works regardless of solar incidence (and in the dark), permitting extended activity in low-light or challenging conditions, at ranges >200m from the sensor. For humans, LiDAR can be used in real-time to aid situational awareness, and point-cloud data can be used to make ultra-high resolution (cm-scale) topography models for traverse planning as well as scientific context. Moreover, through a combination of 6-DoF state-estimation and terrain-relative navigation methods, m-scale-accuracy position tracking can be done in real-time, providing absolute knowledge of the location of assets in the environment.

Frequency Modulated Continuous Wave (FMCW) LiDAR: The FMCW-LiDAR technology is a chip-scale LiDAR that uses coherent laser detection and measures the Doppler shift of a chirped continuous wave to provide velocity, range, and intensity for each XYZ-point in a 3D cloud of points [for detail see 1,2,3]. Ultra-high point density is accomplished for targets both near the scanner and far away through repeated sampling during both static scanning and along traverses, out to distances of hundreds of meters. The FMCW-LiDAR sensing technique's use of coherent detection has the added advantage of being insensitive to direct solar incidence, allowing navigation and mapping regardless of the Sun's position in the sky; thus permitting surface exploration to continue regardless of traverse azimuth and throughout the day (or night).

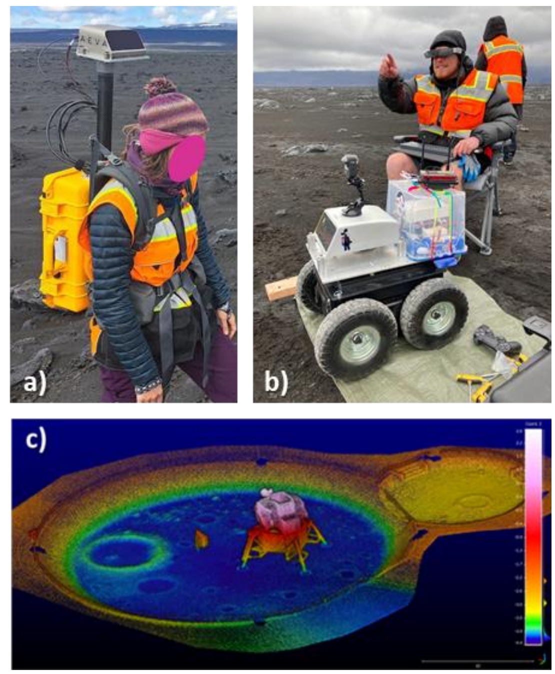

Figure 1: a) the KNaCK mobile LiDAR System with Aeva Aeries 2 velocity-sensing FMCW-LiDAR sensor. b) KNaCAR, autonomous rover, with operator using real-time data visualization in heads-up display for piloting. c) example data of full-size mockup of Apollo LEM. Post-processing of point clouds, ego-velocity, 6-DoF position from FMCW-LiDAR, and inertial navigation data using KNaCK-SLAM allows for GPS-denied topography mapping and traverse path navigation.

The Kinematic Navigation and Cartography Knapsack (KNaCK) LiDAR instrument: Development and testing of the KNaCK LiDAR System

(Fig. 1a,b) uses prototype FMCW-LiDAR sensors developed for the self-driving automotive industry from Aeva, Inc. (Aeries 1 and Aeries 2). The KNaCK system is a backpack/person-mounted platform. Multiple COTS autonomous rover versions of the system (KNaC- Autonomous Rover (KNaCAR, fig 1b)) are also in development. These instruments both serve as development test-articles to evaluate the 6-DoF navigation capabilities of the FMCW-LiDAR for terrain mapping from mobile platforms, provide information about operational methods, and collect test data for GPS-denied algorithm development. Multiple rovers are used to study operations concepts for "swarms" of rovers and human-rover interactions that could enhance scientific return.

KNaCK-SLAM: The simultaneous range and velocity information sampled at each point allows us to develop advanced position-from-velocity simultaneous localization and mapping (SLAM) algorithms and iterative-feedback mechanisms to constrain IMU bias propagation errors. We have developed a novel SLAM solution that makes use of the unique capabilities of FMCW-LiDAR called KNaCK-SLAM (fig. 1c), described in detail in [4]. These solutions represent a significant advancement in spatial-state-estimation for GPS-denied environments, thus making the application of SLAM algorithms more efficient for real-time navigation and mapping.

Acknowledgments: This project is funded by the NASA STMD Early Career Initiative (ECI) program. We also thank Torch Technologies and Aeva, Inc. for their collaboration and support.

References: [1] Zanetti, M. et al., (2022), LPSC 53 Abs #2634. [2] Hexel, et al. (2022) arXiv:2201.11944v2 [cs.RO]31May2022. [3] Poulton et al. (2017) Optics Letters, Vol. 42, Issue 20, pp. 4091-4094. [4] Miller, K., et al., (2022), LPSC 53, Abs# 2808.

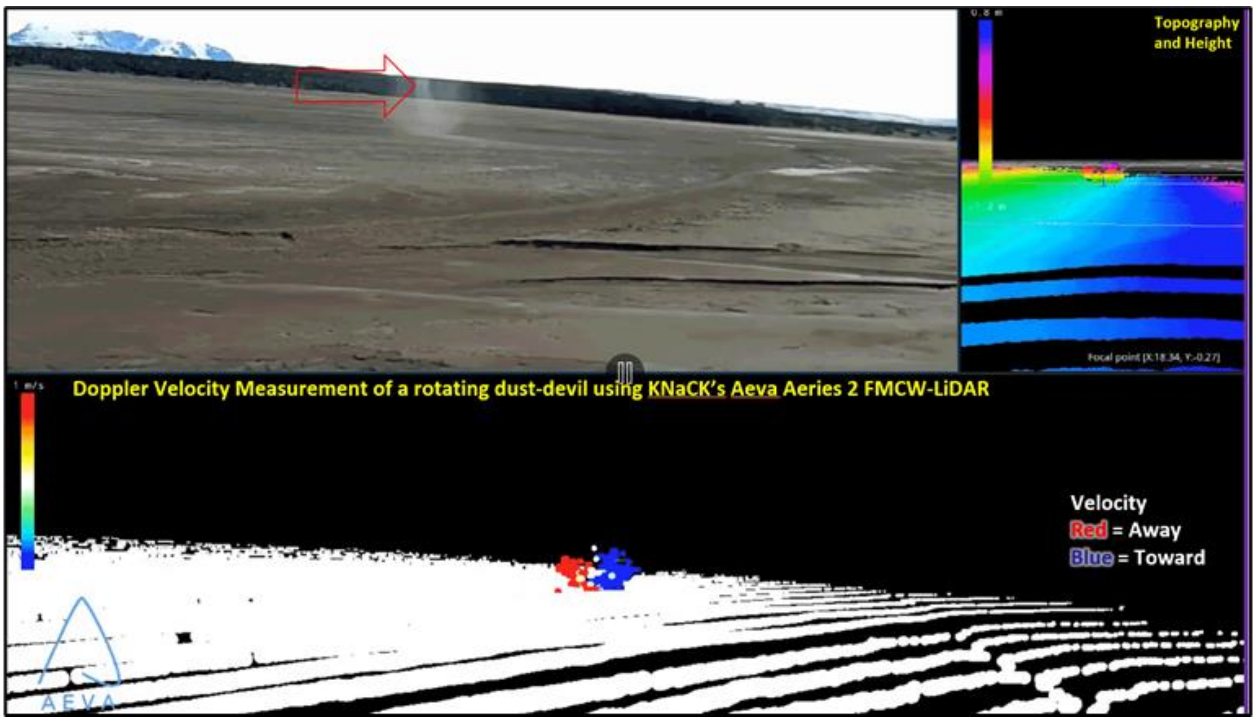

Figure 2: Example data collected by the FMCW-LiDAR sensor on KNaCK (Aeva Aeries 1). This is a still-image snippet of real-time video of rotating dust-devil a glacial sand playa near the Holuhraun flow during the NASA PSTAR Rover and Aerial Vehicle Exploration Network (RAVEN) field campaign in July 2022. The HD Video image (upper left) shows a dust-devil moving from right to left (~S to N). Topography and height (upper right) shows the general topography and slope of the surface and the height of the positive relief of the dust-devil. The velocity-data (bottom) shows the Doppler velocity of the rotating vortex of the dust-devil rotating clockwise. Blue regions are moving toward, red regions are moving away from the sensor (white is no relative motion). Note that the sensor can measure the speed and direction of the vortex. These proof-of-concept results indicate that small-scale atmospheric phenomena can be studied in unprecedented detail, while also providing rover position and navigation data, and topography and morphology mapping data.