FIELD TEST OF ROUTE PLANNING SOFTWARE FOR LUNAR POLAR MISSIONS. A. D. Horchler[1], C. Cunningham[2], H. L. Jones[2], D. Arnett[2], E. Fang[2], E. Amoroso[1], N. Otten[2], F. Kitchell[1], I. Holst[2], G. Rock[1], and W. Whittaker[1,2]. [1]Astrobotic Technology. 2515 Liberty Ave, Pittsburgh, PA 15222. andrew.horchler@astrobotic.com [2]Carnegie Mellon University Robotics Institute. 5000 Forbes Ave, Pittsburgh, PA 15213. red@cmu.edu

Introduction: Limited time, power, and communication constrain rovers that explore and conduct science operations on planetary surfaces. At the lunar poles, this is complicated by the way illumination and communications availability vary across time and space. To make best use of rovers in these difficult environments, efficient planning and sequencing tools are essential.

Spatiotemporal path planning software that accounts for illumination, communications availability, hazard avoidance, and energy usage during route generation has been developed [1], [2]. This software enables mission planners to develop efficient trajectories and sequence multiple science targets. Imprecision in environmental or rover models can be mitigated by risk-tolerant planning, e.g., velocity margins or requiring a minimum distance from shadows. The planning software relies on a physics-based simulation tool, AVOI [3], that uses digital elevation models to render ephemeris-accurate illumination and communications-availability maps.

We have developed a novel field test paradigm to demonstrate and validate planning for a lunar polar environment. An interactive user interface (Fig. 1) was also developed to help users effectively generate and understand plans.

Methods: Simulating the stark low-angled light and sweeping shadows a rover would experience at the poles of the Moon in a relevant environment field test depends on many factors. An artificial lunar landscape, consisting of several 1–2-m high mounds of fine aggregate, was created. Tests were run at night with a 1,000-W spotlight simulating the Sun. To mimic the Sun during the course of a lunar day, the light was towed at a steady pace along a semicircular path.

A LiDAR survey of the 80×80-m field test site was rasterized to 1 cm/pixel and then downsampled to obtain a 0.5-m/pixel elevation map. The properties of the simulated Sun and its approximate position in time were used by the AVOI tool to generate illumination maps (Fig. 2). These were then used in conjunction with the planning software to generate spatiotemporal paths visiting one or more waypoints. Planned paths were uploaded to an AutoKrawler (Fig. 3), a custom 13-kg, 500-W, highly maneuverable rover that operates autonomously, logs data, and transmits live telemetry [4].

Field experiments were designed to demonstrate the software's ability to generate spatiotemporal paths and the ability of risk-tolerant plans to compensate for low resolution maps and imperfect rover control. Test runs

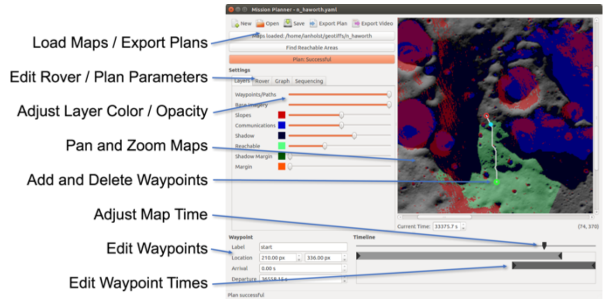

Figure 1. Route planning software user interface.

Figure 2. (Left) Overhead drone images of the field test site and simulated Sun. (Right) Renderings approximating the drone's view and light position.

Figure 3. AutoKrawler rover lit by low angle light.

(N=18) were evaluated based on the percentage of time the rover remained in the light. The rover never entered shadows during risk-tolerant plans, whereas nominal plans sometimes caused the rover to enter shadows when it lagged the intended trajectory or when the light timing was deliberately shifted. Field testing successfully demonstrated and validated our algorithms and software in a realistic lunar polar mission scenario.

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References: [1] Cunningham C. et al. (2016) *LEAG,* Abstr. 5062. [2] Cunningham C. et al. (2017) *IEEE ICRA*. [3] Amoroso E. et al. (2016) *LEAG*, Abstr. 5037. [4] Fang E. et al. (2016) *LEAG*, Abstr. 5026.