A Tale of Two Rovers: Mission Scenarios for Kilometer-Scale Site Survey

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Improvements in navigation autonomy present new opportunities to exploit kilometer-scale autonomous traverses. Here we review field tests of two specific new mission scenarios. The *Scarab* rover demonstrates extreme environment mobility in the context of a site survey mission to characterize lunar regolith in a darkened crater. The *Zoë* platform investigates onboard science data understanding for intelligent, adaptive data collection in a surficial mapping task.

SCARAB: LUNAR REGOLITH SITE SURVEY

Scarab (Figure 1) investigates technologies applicable to a site survey mission to the lunar south pole in advance of human exploration. Regolith coring and analysis would take place in permanently-shaded craters such as Shackleton Crater, where a rover could travel up to several kilometers between sampling sites and deploy an internally-mounted drill to collect samples. This unique operating environment creates several new challenges for rover mobility.

Stable Drilling The rover must carry a dry drilling system and support the drill while it bores. The Scarab platform employs an actuated suspension that lowers the chassis for a wider stance during drilling. In lunar gravity, its 280 kilometer mass produces sufficient downforce to counter the drill's uplift.

Mobility on Slopes and Loose Terrain The lunar crater environment is challenging for autonomous navigation because of steep grades and loose regolith [1]. Scarab's low center of mass facilitates stable ascent of slopes up to 30 degrees. The passive suspension captures body-averaging advantages of rocker-bogie systems. It can alter the angle between wheels on the fly to control vehicle roll and accommodate varying sideslope angles.

Navigation Autonomy and Terrain Analysis Line-of-sight communication with Earth is not possible from within the crater; the rover benefits from navigational autonomy to continue operating between passes of an orbital relay satellite. Scarab incorporates on-board terrain analysis and a path planner to avoid obstacles and rough terrain.

Dark Navigation Dark conditions require special instruments for terrain analysis and localization. A novel sensor mounted to the undercarriage provides active lighting for optical flow calculations and visual odometery (Figure 2). Light-striping identifies obstacles in darkened environments.

Fig. 1. The Scarab rover platform with passive rocker suspension.

Field tests demonstrate sustained autonomous traverses averaging 600m-1000m per command cycle. If powered by a continuous 100W radioisotope supply, a similar platform should be capable of sustained daily traverse ranges on the order of 300m in illuminated or dark terrain. The Scarab mission concept offers a promising approach to first-pass site survey of the lunar south pole.

ZOË: INTELLIGENT SURFICIAL MAPPING

In recent field tests, the Zoë rover (Figure 3) demonstrates adaptive data collection during kilometer-scale mapping of surface material. Here the aim is to validate orbital data by adaptive deployment of a Visible Near-Infrared reflectance spectrometer. Operators specify an traverse goal position at the end of an "exploration corridor." During command execution, the rover explores this corridor as it travels towards the goal waypoint. Zoë demonstrates adaptive data collection in response to trends and anomalies in collected spectra.

In our method the rover builds a statistical model incorporating surface and orbital data, and exploits learned

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Fig. 2. The Scarab rover platform demonstrates optical-flow based visual odometery with active lighting for dark environments.

Fig. 3. The Zoë rover platform.

correlations to improve exploration efficiency. A maximum-entropy sampling strategy guides the rover to the best sample sites, improving map fidelity over static sampling strategies. We demonstrate several component technologies at a basaltic lava flow at Amboy crater in the Mojave desert.

Automatic Spectrum Acquisition Zoë uses onboard pattern analysis to detect rocks in images with up to 90% precision. A visual servoing procedure targets the spectrometer at rocks up to 5 meters away [2]. Tests demonstrate automatic spectrum collection during rover traverse at an average rate of one success per two minutes of rover travel time. The result is a spectral profile of rocks along the rover transect. Figure 4 shows one such profile superimposed on an overflight image of the site. Small dots represent detected rocks, and large colored dots show collected spectra. Dark and light patches in the overflight image correspond to sediment and basaltic lava; these materials match the principal component of variation in the spectral signal. Here we illustrate the mixing proportion with a range of colors from green (basalt) to yellow (sediment).

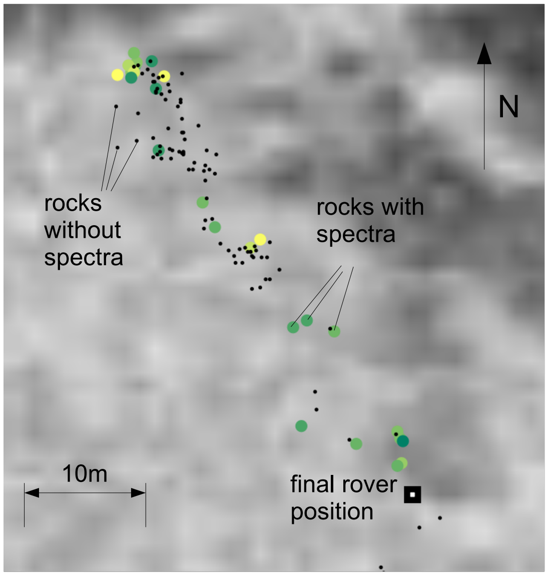

Fig. 4. Spectrometer map generated from a 50m traverse.

Path Planning for Optimal Maps The rover alters its path to target informative areas as it explores. A Gaussian process statistical model extrapolates from previous measurements and orbital sensing, learning spatial and cross-sensor correlations in the data. Its predictions of future measurements guide adaptive path planning. In this manner the rover can alter its exploration plan to recover from navigation errors or respond to unexpected anomalies and trends in data. Tests demonstrate improvements in the fidelity of reconstructed maps over static paths.

Both the Scarab and Zoë field experiments demonstrate new operational modes that leverage rover autonomy for kilometer-scale site survey operations. Future improvements in rover mobility and survivability will continue to present novel opportunities for remote science and exploration.

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