SIMULATED LUNAR ROBOTIC SURVEY AT TERRESTRIAL ANALOG SITES.

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Overview: The "Human-Robot Site Survey" (HRSS) project is a multi-year activity that is investigating techniques for lunar site survey[1]. The system that we are developing coordinates humans and multiple robots in a variety of team configurations and control modes in order to perform comprehensive surface surveys. Site survey involves producing high-quality, high-resolution maps, including 3D surface models, mineralogy, terramechanics, and subsurface stratigraphy. These maps are required for scientific understanding, lunar surface operations planning, in-situ resource utilization and infrastructure emplacement.

In 2006, an initial system was developed using the NASA Ames K9 and K10 rovers and a variety of instruments: the CHAMP microscopic imager[2], a high-resolution color camera, and the Mars Underground Mole subsurface sampler[3]. Aerial mapping (to simulate orbital and descent imagery), 3D terrain modeling (to produce digital elevation maps) and mapping tests were performed at NASA Ames.

What Apollo Could Not Do: During the Apollo program, a variety of scientific instruments were deployed on the lunar surface as part of the Apollo Lunar Surface Experiment Package (ALSEP)[4]. All ALSEP's were deployed in a static configuration, i.e., their data collection did not require any moving parts or any significant mobility across the lunar surface. While deployment requirements were relatively simple, an important class of lunar surface data was left untouched or collected only indirectly: those data requiring significant area coverage and therefore surface mobility for their capture. This includes all data likely to present lateral or vertical variations and, thus require mapping against spatial coordinates.

While remote sensing data acquired from lunar orbit does allow mapping of a wide range of terrain properties (topography, terrain texture and roughness, mineral composition, hydrogen abundance, etc.), spatial resolution is often limited. Topographic anomalies, rock size distributions, and regolith textures vary laterally and vertically on meter to submeter scales, as well as on the meter to kilometer scales commonly accessed by orbital remote sensing. These smaller-scale variations must be documented in order to achieve a detailed understanding of lunar terrains.

On Apollo, such variations on the lunar surface were documented (where possible) via manual photography using spacesuit-mounted cameras. The Apollo astronauts themselves served as instrument-carrying mobile platforms, and the scientific data they acquired placed a significant demand on their EVA time. However, large shadowed areas on the Moon beyond short EVA range could not be imaged, nor could structural variations in the lunar subsurface requiring lengthy transects or wide area survey be characterized.

Return to the Moon: When humans return to the Moon and begin a new wave of sortie missions to the lunar surface late in the next decade, there will be a need to conduct detailed surveys and characterizations of different worksites in order to optimize scientific data collection, prospect for potential resources, and plan safe and productive excursions.

First, and foremost, among anticipated needs will be a detailed characterization of the geology of each site. In particular, comprehensive survey of mineralogy, regolith properties, terrain morphology, and potentially accessible resources will need to be performed. We will need to gain an understanding of the local topography from kilometer to submeter scales, of rock and outcrop occurrences and abundances over multi-kilometer ranges accessible to EVAs, of the variety of regolith surface textures present within similar ranges, and of the surface and subsurface structures and potential resources reachable by astronauts, plausibly down to depths of several meters.

This detailed characterization will need to be carried out at a variety of sites, including possibly over difficult terrain or in locations with challenging environmental conditions (see Figure 1). For instance, in the event of a lunar polar mission, geologic characterization will have to be carried out over rugged, often steeply sloped highland terrain and in the presence of extensively and/or permanently shadowed zones. These mapping activities require dense, systematic coverage of large areas with a variety of instruments.

Figure 1. Comprehensive survey of lunar sites will require systems capable of traversing a variety of terrain and mapping at a range of scales.

Approach: Our approach is to develop and validate system-level concepts for comprehensive site survey in a variety of terrain and over a range of scales. Specifically, we are developing methods that combine information from orbital and descent imagery with surface activity of rovers equipped with survey instruments. In our work, two key topics are being addressed: techniques for robot teams to perform effective survey, and techniques to enable effective human-robot interaction for a range of team configurations.

With our approach, robotic survey tasks can be coordinated from ground-control (for precursor missions), or from inside surface habitats (for sortie missions). A typical scenario involves multiple survey robots mapping a region while human operators assess acquired data and provide physical and cognitive intervention. Coordination and dialogue between ground control, crew (EVA and IVA), and mobile robots uses peer-to-peer human-robot interaction[1], [5].

Our survey architecture is shown in Figure 2. The architecture supports three processing phases: preparation, execution, and analysis. In the preparation phase, we perform terrain modeling by first collecting stereo imagery (aerial or orbital) of the survey terrain. The images are used to create a digital elevation map (DEM), comprising a grid of cells each with an elevation value. Next, a traversability analysis is performed to distinguish safe and hazardous terrain.

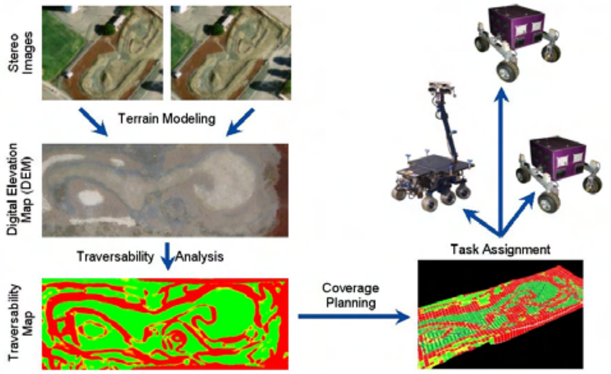

Figure 2. Robotic survey system architecture.

During the execution phase, software components run on-board multiple survey robots and off-board (on ground control stations). The traversability map is processed by a coverage planner, which computes survey points. A task executive coordinates survey point assignment and monitors execution. Survey data is stored in a database for post-processing and analysis with tools including *Mapper/DSS*[6]. Rover activity monitoring and interaction is provided by the *Viz* 3D visualization environment[7] and the *Ensemble* ground systems framework[8].

Current Work: During 2007, we are studying the use of rover-mounted ground penetrating radar (CRUX GPR) [9] to characterize subsurface structure (such as water ice layering) and a 3D lidar (Optech ILRIS-3D) for topographic mapping. These instruments will be integrated on multiple rovers and used for transect surveys in two planetary analog environments: the Marscape testbed at NASA Ames and Haughton Crater (Devon Island, Canada).

Developed for the lunar “Construction & Resource Utilization Explorer” (CRUX) instrument suite, the CRUX GPR is optimized for lunar prospecting: it has relatively shallow penetration (~5-10m depth) and high resolution (15 cm) [9]. The GPR is a short-pulse type system operating at 800-MHz (center frequency), which responds to interfaces between materials of differing dielectric permittivity.

Optech's Intelligent Laser Ranging and Imaging System (ILRIS-3D) is a laser-based imaging and digitizing system designed for commercial survey, engineering, and mining. The ILRIS-3D lidar is approximately the size of a survey total station and has a large dynamic range: from 3 m to more than 1,500m. Prior experiments at Haughton Crater have found that lidar can be helpful for characterization and analysis of remote geological formations.

While the primary focus of our 2007 field work will be validating sensor-rover integration for resource prospecting, we will also begin examining how robot activities can be coordinated from surface habitats or crew rovers and nearby worksites (EVA crew separate from robots). In addition to exploring various operations concepts, we will attempt to quantify resource (cost, mass, intervention, etc.) requirements for human- robot exploration and to collect activity baselines required for analyzing *Mean Time Between Interventions (MTBI)* and *Mean Time to Intervene(MTTI)*[10].

References: [1] Fong, T., Bualat, M., et al. (2006) AIAA-2006-7425. [2] Boynton, J., Mungas, G., et al. (2005). *IEEE Aerospace*, 631-640. [3] Stoker, C., Richter, L., et al. (2003). *6th Intl. Conf. on Mars*, #3007. [4] Bates, J., Lauderdale, W., and Kernaghan, H. (1979). NASA-RP-1036. [5] Fong, T., Nourbakhsh, I., et al. (2005) AIAA-2005-6750. [6] Schlagel, J. and Jensen, H. (2005) *LEAG,* 7. [7] Edwards, L., et al., (2005) *IEEE SMC*. [8] Norris J. S., et al., (2005) *IEEE ICRA*. [9] Kim, S., Carnes, S., et al. (2006). *IEEE Aerospace* [10] Arnold, J., (2006). M.S. thesis, Aero. and Astro. MIT.

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