LUNAR POLAR AUTONOMOUS MICRO-ROVING FOR HYDROGENOUS VOLATILE CHARACTERIZATION.

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Introduction: MoonRanger is an autonomous micro-rover landing at the lunar south pole in December, 2022 to explore for lunar ice. Ice, arguably one of the most valuable resources in the solar system provides opportunities for furthering exploration and habitation by providing an invaluable resource for propellant, oxygen, and water. The MoonRanger rover will fly aboard the Masten XL-1 lander as a part of NASA's Commercial Lander Payload Services (CLPS) program. The technology, rover development, and flight are supported by NASA LSITP. The lunar poles present novel challenges of extreme temperatures and lighting conditions. The MoonRanger rover will be the first to explore the pole, so polar-specific best practices and design considerations are taken into account. This abstract details technical innovations and scientific significance which will provide revolutionary value for near-term and future rover exploration missions. [6]

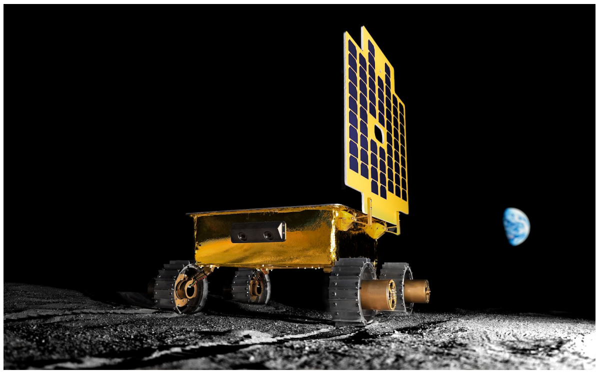

Figure 1. MoonRanger prototype rendered in a lunar-like environment.

Capabilities: In contrast to many large rovers, MoonRanger is a small ~18kg micro-rover with a fast nominal speed of 2.5 cm/s. The rover will explore the south pole of the moon traversing autonomously up to 1km away from a lander location. A Neutron Spectrometry System (NSS), developed by NASA Ames Research Center (ARC), aboard the rover characterizes hydrogenous volatiles within 1m of the lunar surface. With this instrument, MoonRanger will be the first rover to collect rover scale data profiling the existence of lunar ice. The rover itself is four-wheel skid-steered with a vertical solar array and vision systems in both forward and backward driving directions. A belly clearance of 16cm, high-torque motors, and low center of gravity enable MoonRanger to handle ascending slopes of up to 15° and descents of up to 10°.

Innovations:

Autonomy -- Due to MoonRanger's mass limit, heavy radio communication equipment for teleoperation capability is not an option. Instead, MoonRanger communicates to its lander over a WiFi system. For longer range operations outside of lander communication, the rover traverses autonomously [2]. With extreme polar lighting conditions resulting in dark shadows, brightly lit regions, and a mix of both, MoonRanger employs a perception system combining stereo imaging and dot matrix projection to drive in shadowed, well lit, and partially illuminated terrain. The rover navigates terrain via user-generated point clouds from the stereo images it collects. These point clouds are translated into surface models and used by the rover to detect and navigate around any observed obstacles.

Avionics -- MoonRanger's autonomous functionality demands high computing power, previously unheard of in traditional space missions. Therefore, some Commercial Off-The-Shelf (COTS) avionics, such as the Nvidia Tx2 computer, Mipi Cameras, and others provide the necessary performance for the system. These COTS components were selected according to NASA GSFC-STD-8001 guidelines. Many of these components have not yet been rated for space, so extensive testing must be done to ensure these adequately survive the expected environmental conditions. The avionics architecture is organized around both computers, the Tx2i central computer and the ISIS peripheral computer, which share processing functionality. All high-level autonomy is handled by the central computer and all low level tasks, such as commanding other boards and communication with the lander are the responsibility of the peripheral computer. Fig. 2. shows the complete architecture diagram.

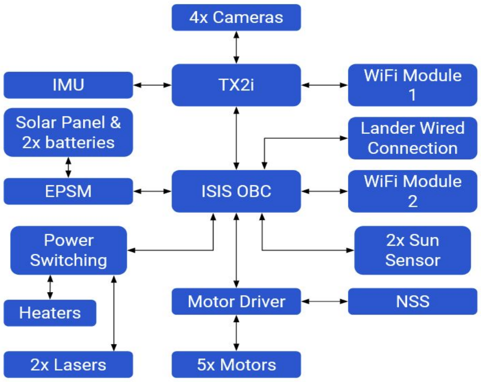

Figure 2. MoonRanger avionics architecture scheme

Thermal -- The lunar south pole is a harsh environment with surface temperatures ranging from 50K to 300K [3] due to low sun elevation. These conditions present challenges for thermal management for a rover with as little thermal mass as MoonRanger. It uses a variety of passive and active thermal control solutions [5], such as Multilayer Insulation (MLI), heaters, and surfaces treated with specialized materials for heat containment or rejection.

Mechanical -- Moonranger's mechanical design consists of a carbon fiber chassis, a honeycomb aluminum radiator, a solar panel module, and four wheel modules. The rover stows and deploys the solar panel on command. During cislunar transit, the solar panel will be stowed and ultimately deployed once the rover is on the lunar surface (Fig. 3). MoonRanger's design is simple and effective, capable of surviving extreme launch vibrations and exhibiting outstanding mobility for its size. In order to survive launch vibrations with limited mass and reduced mechanical risk, the rover's wheels are fixed. To avoid the hazards associated with lunar regolith, dust-sensitive components are mounted within the chassis or sealed to prevent intrusion.

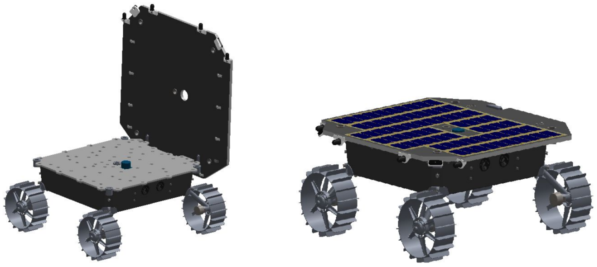

Figure 3. MoonRanger with solar panel in deployed and stowed configurations

Scientific Significance: The NSS payload aboard MoonRanger measures changes in the leakage flux of low energy neutrons which come out of lunar regolith. Observed increases and decreases in this leakage flux can indicate the abundance and depth of hydrogen [1]. With the NSS's readings reaching 1m below the lunar surface, MoonRanger's science operations revolve around near-range waypoints which could support ice at this depth. The mission's three main science goals are to investigate 1) regions which potentially support stable subsurface ice, 2) regions where pumping of ice may have occurred, and 3) investigate small Permanently Shadowed Regions (PSRs) between 1cm and 10m in diameter. Collectively the mission intends to provide the first rover-scale hydrogen characterization on the moon with specific insight focussed on micro-cold traps (small PSRs) and the dependence of lunar ice on time and temperature. Findings from this mission will help validate and inform the only existing datasets pertaining to ice stability which are currently manually constructed using Diviner temperature readings and thermal surface and subsurface modeling. MoonRanger's operations increment in complexity, fully checking out the rover system upon surface deployment and testing out each operation sequence -- teleoperation, autonomy, and science exploration maneuvers. The mission data products will include traverse images, PSRs-targeted images, telemetry, and NSS data readings which profile small PSRs/micro-cold traps and areas with the potential for surface or subsurface stable ice. [3] [4]

Conclusion: This micro-rover mission brings a newer perspective to planetary exploration. MoonRanger will provide new polar context to micro-roving never seen before. The innovations that will result from the mission will enable polar and cold-body-specific micro-roving precedence for future planetary exploration exploration missions. No mission has yet achieved rover-scale data characterization of hydrogenous volatiles. MoonRanger's science return will contribute invaluable insights about geological properties of regolith, the conditions which facilitate stable ice, and possibly context for Earth's own volatile history.

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References: [1] Elphic, R. et. al. "The Resource Prospector Neutron Spectrometer System: RP's Bloodhound," Annual NASA Exploration Science Forum (NESF), October 2017. [2] Kumar, et. al. (2020) i-SAIRAS. "Formulation of Micro-Rover Autonomy Software for Lunar Exploration." [3] P. O. Hayne et al., "Evidence for exposed water ice in the Moon's south polar regions from Lunar Reconnaissance Orbiter ultraviolet albedo and temperature measurements," Icarus, vol. 255, pp. 58–69, Jul. 2015, doi: 10.1016/j.icarus.2015.03.032. [4] M. Siegler, D. Paige, J.-P. Williams, and B. Bills, "Evolution of lunar polar ice stability," Icarus, vol. 255, pp. 78–87, Jul. 2015, doi: 10.1016/j.icarus.2014.09.037. [5] Fisch, et. al. (2020) i-SAIRAS. "Thermal Modeling and Design of a Micro-rover for Lunar Polar Exploration." [6] Schweitzer, et. al. "Micro-Rover Technologies and Mission for Measuring Lunar Polar Ice," IEEE Aerospace Conference, March 2021.