National Aeronautics and Space Administration

Mobility System Evaluation for Traversing Permanently Shadowed Regions on the Moon

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Objectives

- To perform a systematic and quantitative comparison of existing rover designs to determine the most suitable mobility systems for traversing permanently shadowed regions (PSRs) at the lunar southern polar region.
- Multiple traversability and performance metrics: terrain limitations of the mobilty systems, energy efficiency, slip, static stability [2] and path deviation.
- This study was developed to serve as a template for future quantitative mobility trade studies.

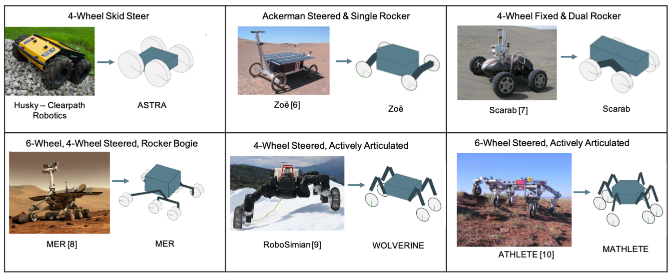

Figure 1: The six planetary exploration rovers and their accompanying simulated rovers that are compared in this study.

Approach

- Evaluation of six different mobility systems with varying masses (10-1000 kg) and terrain types.
- All simulations are performed using the Wheeled Mobile Robot Dynamics Engine (WMRDE) software toolbox described in [1].
- The six mobility systems are inspired by existing rover designs and proposed rover concepts:
  - Four-wheeled single rocker (Zoe [5]),
  - Four-wheeled dual rocker (Scarab [6]),
  - Six-wheeled rocker-bogie (MER [7]),
  - Four-wheeled skid-steered (ASTRA),
  - Four-wheeled actively articulated suspension (RoboSimian [8] / WOLVERINE),
  - Six-wheeled actively articulated suspension (ATHLETE [9]).
- Wheel and joint controllers are implemented for each of these models to best emulate how these systems would be driven in an actual lunar mission.
- A set of simulated terrains are formulated that incorporate terrain profiles based on lunar terrain topography.

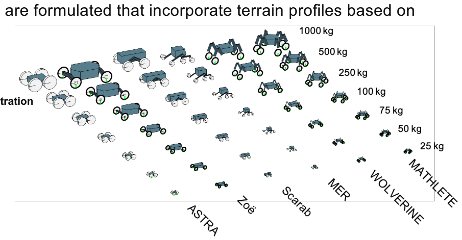

Figure 2: The various simulated rover mobility systems and their different mass classes that were all evaluated.

- Evaluation of rover performance on the various terrains in lunar gravity is performed.
  - Identifies traversability limitations of each mobility system.
  - Relative performance is further quantified on a variety of lunar terrain analogues by comparing energy consumption, slip, static stability [2] and path deviation.

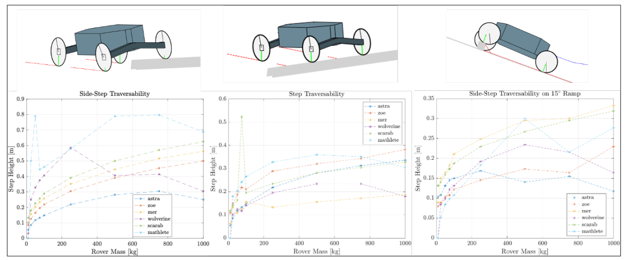

Figure 3: The various simulated rover mobility systems and their different mass classes that were all evaluated in this study.

Results

- Six-wheeled actively articulated suspension system is best performing in most cases.
  - Increased traversability of the actively articulated platforms is attributed to the larger effective wheel radius provided by the large limb workspaces.
  - The limb motion controllers developed for the actively articulated systems only used proprioceptive (force sensor and IMU) feedback. Ideal travesability limitations of the actively articulated systems may be achievable if forward planning based on exteroceptive sensing is augmented with the implemented controller.
- Four-wheeled passively articulated mobility systems have equivalent performance to the flight-proven six-wheeled rocker-bogie suspension system [3] in most cases.
  - In most cases the dual-rocker system was able to traverse larger terrain obstacles than its rocker-bogie and single-rocker counterparts.
  - The rocker-bogie demonstrates best performance due to its increased articulation when considering wheel radius to step height ratios.
  - In regards to energy, slip and pose deviation however, the single-rocker system typically outperformed the other passively articulated suspension systems on all terrains and contact models across all mass classes.
- Software framework provided enabling further mobility system simulation-based evaluations.
- Evaluations performed use the MATLAB-based WMRDE software providing relative ease-of-use.

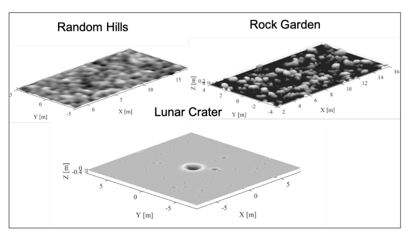

Figure 3: The three simulated lunar-surface terrains used to evaluate traverse performance for each of the rover mobility systems.

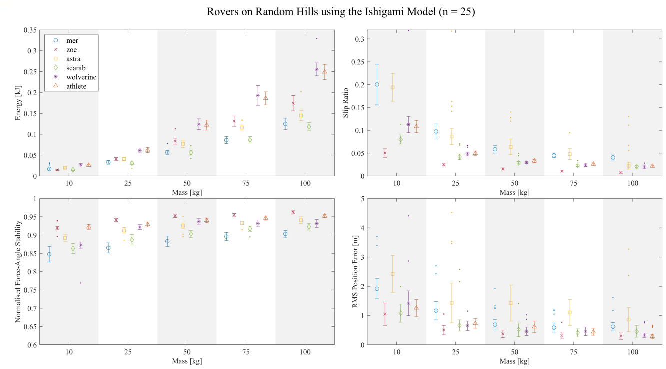

Figure 4: Performance results from all rovers with masses 10-100 kg driving over the Random Hills terrain with a compliant soil wheel-terrain contact model [3].

Significance/Benefits to JPL and NASA

- Results show a simulation-based quantitative comparison of existing planetary exploration rover designs, and an analysis of their suitability for traversing terrain similar to what would be found in lunar PSRs.
- Significant to NASA/JPL given the renewed interest for in situ exploration of the southern polar PSRs on the Moon.
- The results from this study provide expected first-order performance data for candidate mobility solutions for upcoming rover missions.
- The simulation framework established in this work may be extended to future mobility studies that wish to conduct more refined mobility system comparisons applied to a specific surface mission.

Publications

Clyde Webster and William Reid. "A Comparative Rover Mobility Evaluation for Traversing Permanently Shadowed Regions on the Moon." Submitted to IEEE Aerospace (2022).

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