Enabling New Exploration Opportunities on Planetary Surfaces

Robert. C. Anderson and Issa A. Nesnas, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, Robert.C.Anderson@jpl.nasa.gov

Motivation

Recent observations of planetary bodies have revealed surface activities that have intrigued the science community. Image sequences of Saturn's moon Enceladus have shown what appears to be icy particles ejecting from its south polar regions. High resolutions images from the Mars Global Surveyor and the Mars Reconnaissance Orbiter have captured recent activities on the interior of crater walls. The most recent discovery of recurring flows in the warm seasons on Mars suggest briny water flows on the steep slopes of the crater walls, such as Newton crater. Exploring such sites on Mars could help answer questions as to whether life ever existed on Mars or whether it could still be present. Analysis of ejected debris following the impact from the LCROSS experiment of the LRO mission suggest the presence of water ice in the Moon's permanently shadowed Cabeus Crater.

Figure 1: The Axel rover exploring a near vertical cliff

These recent water ice discoveries emanate from sites that are currently inaccessible for in-situ exploration. Such terrains present unsurmountable challenges for state-of-the-art planetary rovers. These sites have very rugged terrains, which present challenges for both landing and roving its plains. However, the potentially rich science return has motivated the investigation of novel robotic explorers that would be able to access, measure and sample such sites.

Challenges

Concepts for missions that target science investigations in extreme terrains such as canyons, deep crater, gullies, and fissures date back several decades. Such target destination present formidable challenges for in-situ exploration. Continuous observations and analysis of orbital data from such sites underscore the scientific potential of these rich targets.

Chief among the challenges for sustainable exploration is overcoming terrain topographies. Such terrains present steep slopes, rugged topographies and numerous obstacles. Mobility across such steep and rugged terrains not only demands a high level of robustness to overcome challenging features, but also an ability to recover from failures such as: tipping over, driving into sand traps, similar to the one that ensared the Spirit rover, or high centering on a rock. In addition to the challenges of terrain topography, other challenges such as power and communication must be addressed especially as crevices and crater walls could occlude direct line of site needed for communication and occlude direct sunlight for solar energy. Additionally, environmental challenges such as extreme temperatures of cold traps or Lunar dust would need to be addressed.

Approach

A family of robotic vehicles, termed the Axel rovers, was developed over the past decade to overcome some of the challenges of exploring extreme terrains. The Axel rovers use a minimalist approach with novel designs that offer versatile features while reducing overall complexity. The fundamental concept behind Axel is to use a minimalist rover with large accommodations for science instruments to explore the extreme terrains. Axel is designed to be a tethered marsupial that will be deployed from a lander or from a rover, which provides it with power and communication.

The rover Axel is a two-wheeled vehicle with symmetric body two large science bays and a castor arm. Because the primary goal is minimal complexity, the Axel rover uses only four actuators to control its wheels, its arm, and its spool for managing the tether. A single Axel can carry and position/orient six to eight instruments on different terrain topographies.

With its four aligned actuators and a tether, Axel is capable of traversing very steep slopes, following arbitrary paths, turning-in-place, and operating upside-down or right-side-up. With its tether, it is capable of driving down and up steep crater walls and lowering itself down from overhands using the same actuators to reel and unreel the tether around its cylindrical body. Using a special wheel design with grousers, Axel can overcome obstacles that are larger than a wheel radius and tolerate strong impacts during landing or rover. Figure 1 shows the Axel rover rappelling down steep slopes and traversing rocky terrain.

Axel's design co-locates its instruments, sensors, actuators, and electronics inside its central body. This configuration provides compactness for launch, and robustness against environmental extremes in planetary missions. The Axel rover is equipped with computational and communication modules, stereo cameras, and an inertial sensor for autonomous navigation with obstacle avoidance.

The DuAxel rover is a four-wheeled vehicle formed from two Axel rovers, provides untethered mobility on extreme terrains. Both the Axel and DuAxel rovers enjoy a level of redundancy that improves its robustness for exploring extreme terrains. With a target mass of 10-20 kg for each Axel and 80 – 120 kg for the DuAxel, such a platform could possible fit within the scope of a future Discovery mission or as part of a mobile science payload hosted on another mission.

Results

We have implemented and fielded three generations of Axel rovers. We will present the results of these field tests showcasing Axel and DuAxel's extreme-terrain performance as evaluated during two recent field tests in a steeply sloped Southern California rock quarry and at an Arizona location that closely resembles rugged Martian terrain. We also summarize lessons learned during the Axel development program to embody and discuss some potential future missions that would provide in-situ access to explore science rich targets.