Title:

Autonomous Surface Mobility on Small Solar System Bodies with Hopping/Tumbling Rovers

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Abstract:

The future in-situ exploration of small Solar System bodies requires robotic platforms capable of controlled surface mobility. In the microgravity environment of small bodies such as asteroids, comets or small icy moons, conventional wheeled rovers are quite ineffective due to the low frictional forces on the ground. Through a joint collaboration between Stanford University, JPL, and MIT, we have been developing a small, minimalistic rover, called "Hedgehog", which extends the idea of *internal actuation*, previously developed for landers on the Hayabusa II mission, to an architecture that enables *controlled* surface mobility in microgravity. Specifically, by applying torques to three internal flywheels with motors and mechanical brakes, Hedgehog is capable of performing attitude-controlled hops for large surface coverage, "tumbling" maneuvers for fine local mobility, and precise shifts in orientation to point instruments. Such a mobility approach is critically enabled by the microgravity environment of small bodies, whereby small surface contact forces can produce long-range ballistic flight.

We have demonstrated controlled mobility in simulation, in a high fidelity microgravity test bed, and onboard NASA parabolic flights. However, navigating a hopping rover to points of interest on the surface of distant bodies requires more than just controlled maneuvers. It also requires an autonomy stack that allows the rover operate independently without continuous communication with ground stations—specifically, the ability to localize itself on the surface and plan safe trajectories in a potentially hazardous environment. We adapt concepts from the fields of vision-based localization and reinforcement learning in robotics for the unique visual environment on the surface of small bodies and for the highly stochastic dynamics of hopping and bouncing.

This concept has the potential to lead to small, quasi-expendable, and maneuverable rovers that enable a focused, yet compelling set of science objectives aligned with interests in planetary science and human exploration. Moreover, this new paradigm of mobility for "nanorovers" is highly scalable within typical CubeSat sizes from 1U to 27U, allowing many of the subsystems to be leveraged from interplanetary CubeSats being developed at JPL (e.g., C&DH/avionics boards from NEA Scout, UHF telecom system from INSPIRE, and electrical power system from MarCO). We present a notional mission architecture to Phobos that addresses both high-priority science identified for Mars' moons and strategic knowledge gaps for the future Human exploration in the Martian system.

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Keywords:

Microgravity / Rover / Small Bodies / In-situ Science / Phobos