Hedgehog - A Minimalistic Robot for In-situ Exploration of Small Bodies

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Project Objective:

To **develop** a low-mass minimally-complex **robotic platform** for the *in situ* exploration of small bodies capable of:

•**Large surface coverage** (on the order of *km*²)

•**Finely-controlled regional mobility** on the order of *20%–30% accuracy of traverse distance.*

Benefits to NASA and JPL:

- Provides JPL/NASA with a low-mass capability for *in situ* surface investigations at both large and fine scales (from kilometers to meters)
- Enables physical and chemical characterization of surface properties relevant to both human and science exploration missions

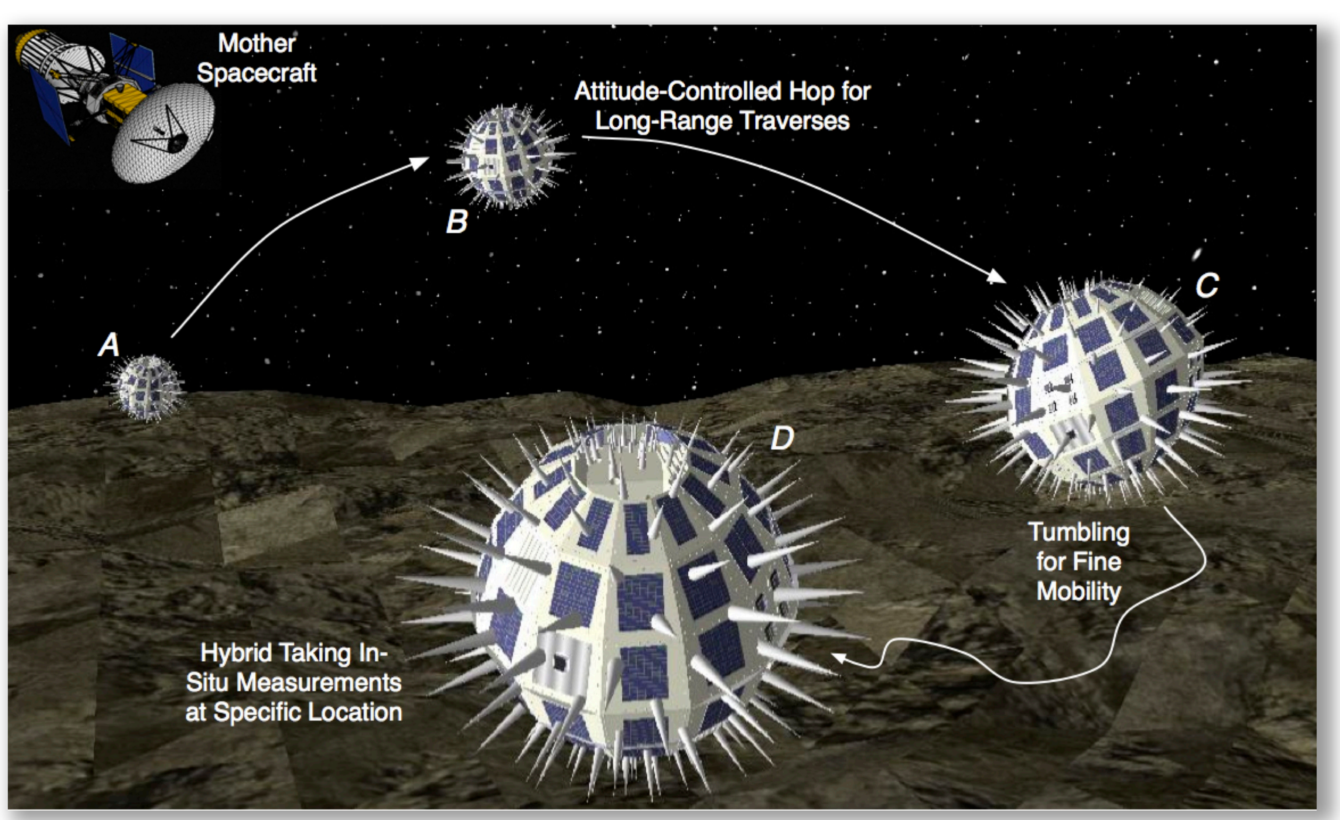
FY13 Results:

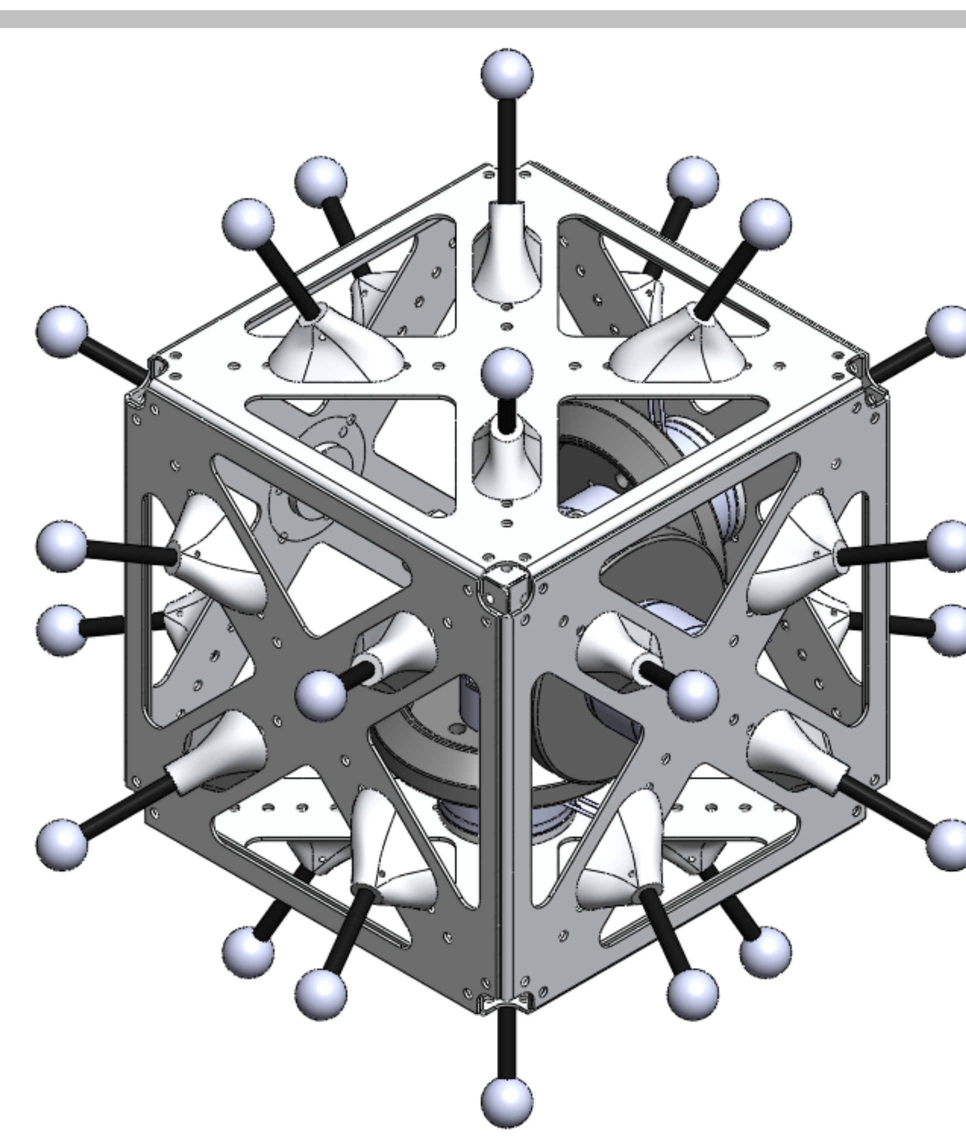
Theory, models and simulations

- **Investigated dynamics** of a platform with three mutually-orthogonal flywheels over undulated terrain using M3tk (JPL-developed multi-body dynamics simulation in C++)
- **Developed equations** of motion using Lagrangian mechanics to analyze different states of spike/terrain contact models
- **Conducted** granular media **simulations experiments** using GRAMMS to simulate regolith/platform contact dynamics with millions of particles using lunar regolith properties

Prototype and experiments

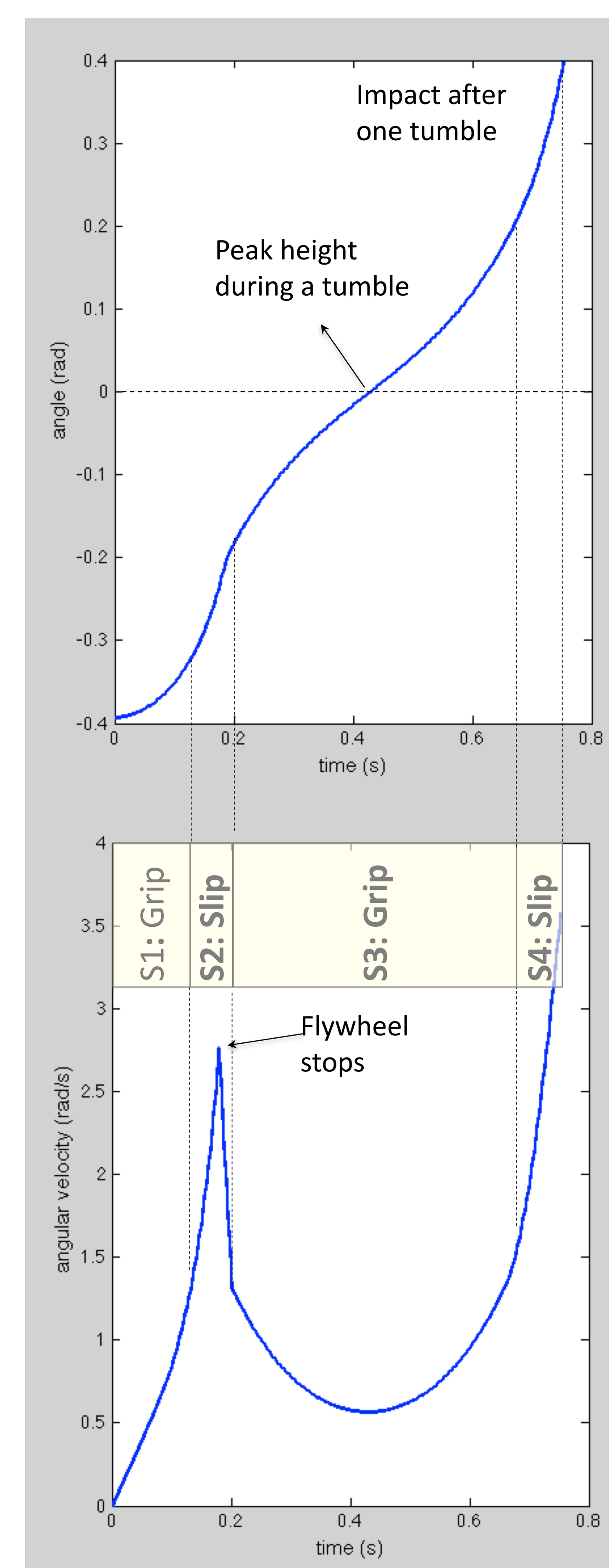
- Completed design and fabrication of a three DOF prototype with flywheels and brakes, and avionics that provide on-board computation, image acquisition, motion control, and communication
- Demonstrated up to eight controlled tumbles in multiple directions under Earth's gravity by commanding a sequence of braking motions
- Conducted tumbling/hopping experiments on flat and sandy surfaces using a gravity offloading test bed to compare motions to current simulated Lagrangian models



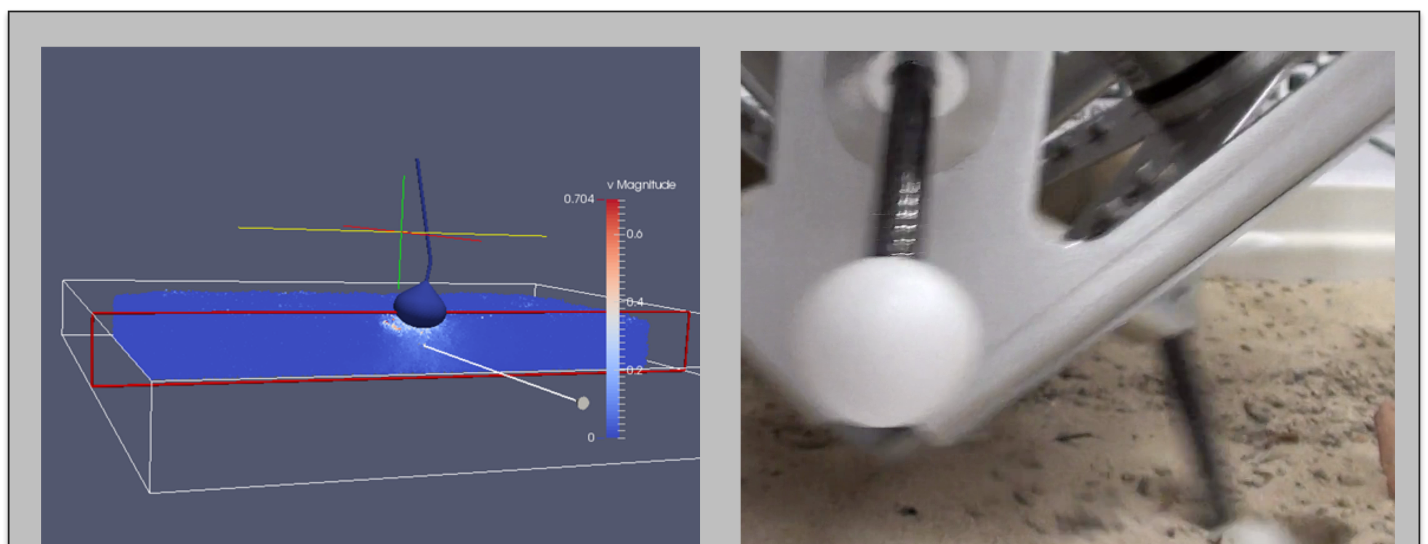


3 DoF Hedgehog Prototype

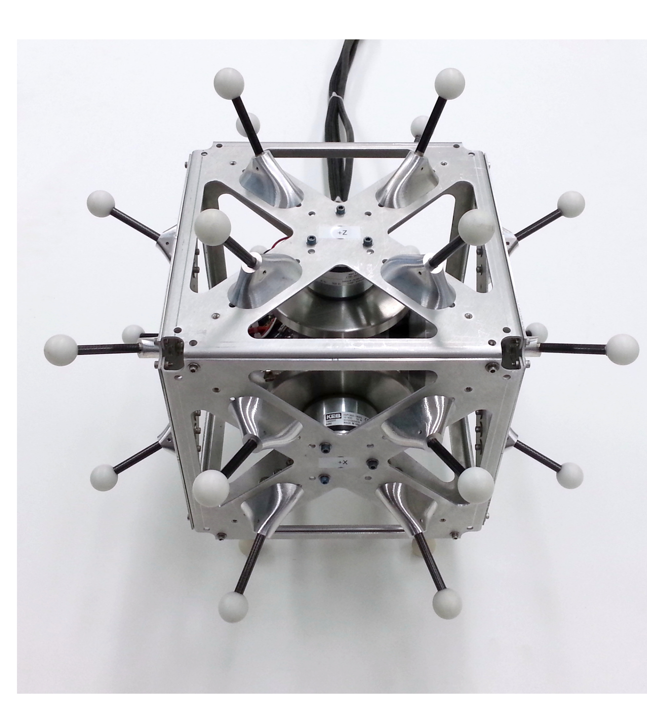
Mass = 5.3 kg (w/ 3 flywheels w/ external avionics)
Size = 0.2 m x 0.2 m x 0.2 m (excludes spikes)
Spike length = 0.085 m (tip at 0.19 m radius from center)

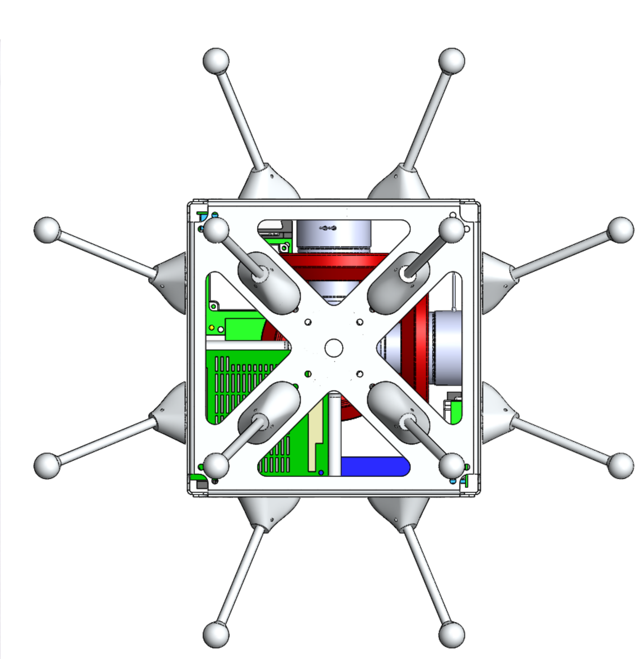


State transitions for spike/terrain contact on a flat surface



Comparing granular media simulation of spike/terrain contact with physical experiments





With avionics

Publications:

- M. Pavone, J.C. Castillo-Rogez, I.A. Nesnas, and J. Hoffman, "Observational Strategies for the Exploration of Small Solar System Bodies," *IEEE Aerospace Conference*, Montana, March 2012
- R. Allen, M. Pavone, C. McQuin, I. Nesnas, J. Castillo, T. Nguyen, J. Hoffman, "Internally-Actuated Planetary Rovers: Theory and Experimentation," Int'l Conf on Robotics and Automation, Sept 2012
- A. Koenig, M. Pavone, J. Castillo, I. Nesnas, "A Dynamical Characterization of Internally-Actuated Microgravity Mobility Systems," Int'l Conf on Robotics and Automation, 2014 (submitted)
- I.A. Nesnas, M. Pavone, J.C. Castillo-Rogez, "Affordable Surface Mobility for Microgravity Bodies Using Hopping / Tumbling Robots," Low-Cost Planetary Mission Conference, June 2013

Advancing state-of-the-art

Investigating multi-modal mobility using hopping, tumbling and attitude-controlled hops (future work) for small bodies for large coverage and precise maneuvers on small bodies

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