Effects of probe shape and surface topography in deployment to small bodies

Stefaan Van wal
Daniel Scheeres

15th International Planetary Probe Workshop
June 14th, 2018
Boulder, Colorado
Small-body exploration

- Current baseline: remote sensing operations
- Increased return: *surface exploration*
Surface exploration: Past

- Minerva-I (Hayabusa-1)

- Philae (Rosetta)

Lander deployment is challenging!
Hayabusa-2:
- Minerva-II and Mascot rovers

- Deployed before Hayabusa-2 sample acquisition
- Rovers must avoid sampling site exclusion zone

Planning of rover deployment requires simulation of bouncing trajectories
Modeling: Shape

- Signed distance field (SDF):
  - Implicit shape model
  - Gridded 3D sampling of distance function \( d(x) \)
  - Linearly interpolated to yield \( d(x) \) and \( N(x) = \nabla d(x) \)
  - Inexpensive collision detection vs. classical polyhedron model
Modeling: Surface features

- Asteroids and comets are covered with rocks of various sizes
- Global shape models are smooth with only large features
- Example: Itokawa

- Presence can affect motion of a probe
- How to account for millions/billions of rocks?
Modeling: Surface features

- Procedurally seeded rocks:
  - Aperiodic tiling of seeding texture
  - Texture can be tuned to match observations
  - Numerical cost is two additional SDF samplings
  - Example of different rock populations:
Modeling: Gravity

❖ Voxelized gravity field:
  ➢ Pre-compute polyhedron gravity $g(x)$ at 3D mesh points
  ➢ Interpolate gravitational perturbation $\Delta g(x) = g(x) - (\mu/r^3)x$ at field point $x$
  ➢ Inexpensive evaluation of complex gravity field
Modeling: Contact

- Hard contact model with normal and friction forces:
  - The forces are coupled for *eccentric* collisions!
  - Numerical integration is required to evaluate effect
  - Based on model by Stronge
- Model is governed by:
  - Coefficient of restitution $e$ and friction $f$
  - Assumed independent of velocity and attitude
- Distinguish between slip and stick of contact point
- Impulsive collision *vs.* continued contact motion
A single simulation
A batch of simulations

- Parallel implementation on GPU enables broad studies

**surface dispersion**

**settling time**
Effect of lander shape

- Repeat nominal scenario for different shapes:

- Different shapes experience notably different dynamics!
- Implications for lander design
Effect of lander shape

- Behavior of Minerva-II-1:

- Presence of rocks?
Effect of rocks

- Using procedurally seeded rocks, varying spatial density $k_0$:
  - Settling time statistics:
    - Rocks resist the ‘rolling’ motion of a probe
    - They are important to model!
    - Results hold for normal & grazing impacts
    - Implications for Minerva-II-1 rover
Effect of mass distribution

- Repeat nominal scenarios for varying $j$:

- Further implications for lander design
Questions?

stefaan.vanwal@colorado.edu