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High-Fidelity Simulation of Small-Body Lander/Rover Spacecraft (Draft)

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The scientific return of spacecraft missions that explore solar system small bodies can be increased through the inclusion of surface exploration with deployed probes. In this dissertation, a methodology is presented that allows for fast, parallel simulation of bouncing trajectories of arbitrary-shaped ballistic probes in the small-body environment. This enables planning of probe deployment and operation, and supports their inclusion on future missions.

The coarse small-body shape is modeled using an implicit signed distance field (SDF) that allows for fast collision detection. Statistical features are included onto the SDF using procedural generation techniques. The small-body gravity field is captured using a voxelization of the classical constant-density polyhedron. Surface interactions between a probe and the surface are accounted for using a hard contact model that takes into account restitution and friction. These models are implemented in a GPU environment to allow for the parallel execution of multiple trajectories.

The developed simulation framework is applied to perform parametric investigations of probe deployment, which quantify the effects of relevant properties of a probe and its target small body. The probe shape and internal mass distribution are found to strongly affect its deployment dynamics, with near-spherical probes dispersing over greater regions than more distorted shapes. The effect of the surface interactions coefficients on the different shapes variants is quantified. The presence of statistical surface features is also shown to further influence probe dynamics.

Finally, the framework is applied to perform a pre-arrival deployment analysis of the MINERVA-II rovers onboard the Hayabusa-2 spacecraft. This analysis identified challenges in the rover deployment and was used to redesign aspects of the nominal rover release sequence. These models will be used to inform the target site selection and follow-on analysis for the Hayabusa-2 mission rover deployments.