Surovik, David Allen (Ph.D., Aerospace Engineering Sciences)

Autonomous Mission Design in Extreme Orbit Environments

Thesis directed by Prof. Daniel J. Scheeres

An algorithm for autonomous online mission design at asteroids, comets, and small moons is developed to meet the novel challenges of their complex non-Keplerian orbit environments, which render traditional methods inapplicable. The core concept of abstract reachability analysis, in which a set of impulsive maneuvering options is mapped onto a space of high-level mission outcomes, is applied to enable goal-oriented decision-making with robustness to uncertainty. These nuanced analyses are efficiently computed by utilizing a heuristic-based adaptive sampling scheme that either maximizes an objective function for autonomous planning or resolves details of interest for preliminary analysis and general study. Illustrative examples reveal the chaotic nature of small body systems through the structure of various families of reachable orbits, such as those that facilitate close-range observation of targeted surface locations or achieve soft impact upon them.

In order to fulfill extensive sets of observation tasks, the single-maneuver design method is implemented in a receding-horizon framework such that a complete mission is constructed on-the-fly one piece at a time. Long-term performance and convergence are assured by augmenting the objective function with a prospect heuristic, which approximates the likelihood that a reachable end-state will benefit the subsequent planning horizon. When state and model uncertainty produce larger trajectory deviations than were anticipated, the next control horizon is advanced to allow for corrective action — a low-frequency form of feedback control. Through Monte Carlo analysis, the planning algorithm is ultimately demonstrated to produce mission profiles that vary drastically in their physical paths but nonetheless consistently complete all goals, suggesting a high degree of flexibility. It is further shown that the objective function can be tuned to preferentially minimize fuel cost or mission duration, as well as to optimize performance under different levels of uncertainty by appropriately balancing the mitigation paradigms of robust planning and reactive execution.