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TRAJECTORY OPTIMIZATION FOR SHORT-RANGE TUMBLING MANEUVERS AND HOPPING ROVERS

Abstract

There has been growing interest in utilizing hopping and tumbling maneuvers in robotic exploration missions to planetary bodies. A wide variety of missions have been proposed, including passive approaches such as tumbling landers, as well as internally activated hopping vehicles. These navigation modalities provide numerous advantages over conventional wheeled rovers in environments with rugged terrain and reduced gravity. However, planning trajectories that include tumbling is a challenging problem as it requires a consideration of complex vehicle dynamics comprising both free-fall and impact-response over a highly variable terrain. We seek to address this problem through the development of a novel optimal trajectory planning formulation for short-range hopping and tumbling maneuvers over a static gravity field. The landscape surrounding the vehicle is approximated with a polyhedral mesh containing N flat surfaces. A collision model is developed to characterize the response of the vehicle with respect to the relative state parameters on impact. The tumbling dynamics are then represented as a hybrid system comprising a single free-flight mode and N collision-response modes. The dynamics model and vehicle constraints are incorporated into a mixed integer programming (MIP) framework. Here, integer variables are used to encode the mode of the vehicle. Collision states are activated when the ballistic trajectory is predicted to intersect with a given surface, and the appropriate collision response mode becomes active. The resulting formulation allows the initial hopping state parameters to be optimized subject to the dynamic constraints, vehicle limitations, and with consideration of obstacle avoidance regions. The high-level planning scheme proposed is applicable to cases where a vehicle is able to generate a controlled hop from rest, and where the impact parameters of a descending vehicle must be chosen in such a way that accounts for passive tumbling behavior. Though the current formulation of the planning problem assumes simplified and deterministic dynamics, a key advantage to the mixed integer programming approach developed is that the problem can be solved to global optimality using off-the-shelf optimization solvers. An experimental validation of the collision-inclusive MIP has been conducted on a 3-DOF microgravity testbed.