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SAFETY VERIFICATION OF POWERED DESCENT GUIDANCE BASED ON FUNNELS

Abstract

In pursuit of the scientific research value, the future exploration missions of the Moon, Mars and other planets may require landing in areas with hazard terrains, which imposes more demanding requirements on the capability of autonomous obstacle avoidance and accurate landing. In this paper, with the sums-of-squares programming as the key computational tool, a landing safety assessment scheme based on the finite-time invariance regions (funnel) of the closed-loop system is proposed, mainly including three parts of trajectory planning, tracking controller design and funnel estimation. First, the convex optimization method is used to get the nominal landing trajectory. Subsequently, the state feedback controller is designed near the nominal trajectory to form a closed-loop system. To comply with the specifications of the sums-of-squares programming, the closed-loop system is then approximated as a polynomial system. Mathematically, the funnel can be described as a sub-level set of a time-varying positive definite function about the state quantity, whose derivative with respect to time needs to satisfy specific inequality constraints. The funnel estimation of the closed-loop system is formulated as a sums-of-squares programming problem, which boils down to a semidefinite programming problem and can be solved efficiently by interior point methods. The funnel is essentially an outer approximation of the real reachable set of the closed-loop system during the landing process, which reflects the propagation result of the initial state uncertainty. If there is no intersection between the funnel and terrain obstacles, the landing safety is guaranteed with the designed tracking controller. Simulation results of the classical Mars landing model are presented, which demonstrate the effectiveness and reliability of the proposed scheme.