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NON-GAUSSIAN CHANCE-CONSTRAINED TRAJECTORY FOR SPACECRAFT RENDEZVOUS AND DOCKING USING GAUSSIAN MIXTURES

Abstract

Trajectory optimization plays an important role in spacecraft missions since it can ensure the satisfaction of constraints on states and control inputs and the optimality in predefined criteria, such as fuel consumption. In real missions, dynamic models are usually affected by disturbances, e.g., process noise and uncertainties in state measurements. Optimization with consideration of uncertainties can greatly improve the performance of closed-loop trajectories. Most of the existing stochastic trajectory optimization algorithms rely on the assumption that the state uncertainties are Gaussian distributions. In real systems, however, the assumption does not hold when the dynamics is highly nonlinear. It is of great importance to consider the effects of non-Gaussian uncertainties on trajectory optimization.

This paper proposes a novel stochastic trajectory method with non-Gaussian chance constraints to address the nonlinear problem of 6-DOF spacecraft rendezvous and docking in the presence of nonlinear chance constraints. In the problem, the disturbances are described by martingale process, and the constraints on collision avoidance, sensor field-of-view, and control magnitude are considered as chance constraints. Due to the nonlinear dynamics, the state distributions along the dynamics are non-Gaussian even though the initial state is Gaussian.

The main difficult in the problem is to approximate the non-Gaussian distributions with a tractable way. Thus, Gaussian mixture model (GMM) is utilized to quantify the uncertainty propagation since it is useful tool in approximating distributions and has inherited the good properties of Gaussian distributions. A feedback control is combined to the nominal trajectory to prevent states from the dispersion induced by disturbances, where the feedback gain is sampled from a GMM. By the uncertainty propagation under the feedback control, the nonlinear stochastic dynamics are transformed into equality constraints on the first two moments of the states. The chance constraints are approximated by deterministic constraints according to the characteristic functions of GMM, which is then converted into convex constraints by introducing auxiliary variables. Further, a successive convex programming algorithm is presented to iteratively solve the nonlinear stochastic optimization problem.

Based on the proposed optimization algorithm, the stochastic optimal trajectory is calculated in numerical simulation using the convex programming solver MOSEK. Numerical results indicate that the proposed algorithm is more accurate compared to Gaussian based methods when dealing with nonlinear stochastic dynamics. The proposed algorithm can provide an alternative scheme in dealing with stochastic uncertainties with predefined reliability in future rendezvous or on-orbit service missions.