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DESENSITIZED ENSEMBLE GUIDANCE

Abstract

Robust trajectory optimization is a critical technology that can reduce the risk of the mission failure while maximizing the expected performance. Current literature is based on the use of heuristic optimization algorithms with uncertainty propagation algorithms like Improved Latin Hypercube Sampling and Stochastic Collocation and nonlinear programming with a robust trajectory formulation based on non-intrusive Polynomial Chaos Expansion (PCE) methods like Stochastic Collocation. However, both methodologies generate open-loop solutions with high computational requirements and can't be extended upon high-dimensional complex uncertainties, especially the time-varying ones. One such approach that can reduce the impact of time-varying uncertainties is the desensitized optimal control, in which only the reference solution and its sensitivity matrix is propagated, meaning that the path constraints can't be treated for dispersed trajectories.

A novel computational framework called the Desensitized Ensemble Guidance is developed that can circumvent the drawbacks of PCE-based formulations, Unscented Guidance and Desensitized Optimal Control by utilizing Ensemble Optimal Control to accomplish best of both worlds. Sensitivity formulation is included for each sampled trajectory to reduce the impact of time-varying stochastic uncertainties on the objective function and the path constraints, which could only be accounted for inside of the Unscented Guidance methodology by sampling time-varying pseudo-random tychastic variables. Ensemble optimal control is utilized to formulate a sampling-based optimal control problem under aleatoric and epistemic uncertainties to ensure the satisfaction of path and endpoint constraints while trading off robustness with the optimality of the results. Simulations are conducted via leveraging pseudospectral transcription, a sparse-grid based approach called Conjugate Unscented Transformation and an interior-point nonlinear programming inside of a tailored optimal control software based on a vectorized formulation of the resulting robust trajectory optimization problem.

Benchmark problems based on Zermelo's boat problem and planetary-entry are solved under high-dimensional uncertainties including time-dependent uncertainties, navigational errors and model uncertainties. Solution of these problems are proven to be optimal by comparing co-states and the Hamiltonian with the derived optimality conditions. Additional to the open-loop solutions, a new control term called the recovery control is optimized for the closed-loop implementation of the proposed computational architecture. The robustness of this approach is shown with a Monte Carlo analysis.