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Author: Ms. Allegra Farrar
Massachusetts Institute of Technology (MIT), United States

AN ITERATIVE LQR METHOD FOR ADDRESSING MODEL UNCERTAINTY IN THE PLANETARY ENTRY PROBLEM

Abstract

Set by NASA as the future destinations beyond Earth orbit, the Moon and Mars present significant challenges to the entry, landing and descent sequence. Missions including sample return and human exploration require precise landing accuracy. Additionally, entry vehicle dynamics and atmospheric parameters at time of flight are hard to predict. This along with the advancement of mission objectives invoke the need for a reliable, robust, and computationally reasonable method with certifiable guarantees of safe landing. Therefore, this paper presents a closed-loop trajectory optimizer capable of incorporating the atmospheric models and navigational data uncertainty for the nonlinear dynamics of hypersonic entry by applying an iterative Linear-Quadradic-Regulator (iLQR).

iLQR is an efficient and powerful method for trajectory optimization derived from Differential Dynamic Programming (DDP) principles. DDP algorithms have been applied successfully in cases of robotic movement to locally improve upon a single trajectory through second-order convergence for a local optimal trajectory. iLQR takes this method a step further by iteratively linearizing the system dynamics through a forward pass around the current nominal trajectory for which a local optimal control law can be determined through a backwards pass. By performing these steps iteratively, the program will converge to determine an optimal trajectory by minimizing the performance cost and the uncertainty in the dynamics model.

Of the optimization work done for planetary entry and landing trajectories, few studies incorporate uncertainty as part of the optimizer. Devising a concrete method for quantifying the uncertainty of the model is critically important for establishing trajectory robustness and performance safety measures. By closing the loop on a trajectory optimizer through applying iLQR, this method proposes an algorithm that allows for performance efficiency and control of a system with complex nonlinear dynamics. While most iLQR formulations are restricted to unconstrained problems, this approach applies both model and control constraints within the coefficient matrices of the cost function.

To demonstrate its effectiveness, the algorithm will be tested against a series of realistic simulations to test the model performance against mission requirements, such as precision landing. Results are expected to show an efficient data-driven algorithm capable of learning how to successfully control a crewed-scale spacecraft, 40 tons, for lunar landing and Mars entry under dynamical uncertainties. Additionally, given system performance parameters, the covariance of the final position (landing accuracy) can be determined from the algorithm and the results can be used to determine safe parameter ranges that achieve the desired accuracy.