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RIEMANNIAN OPTIMIZATION FOR SPACECRAFT TRAJECTORY DESIGN

Abstract

This paper proposes a new method to solve optimization problems of spacecraft trajectory with constraints. In designing spacecraft trajectory, it is important to minimize the fuel consumption because the payload of spacecraft is limited. Although low thrust propulsion system has been used in a variety of missions, designing optimal trajectory is burdensome. This difficulty is introduced by long transfer time and sensitivity to the initial value. The problem of optimal trajectory design with continuous low-thrust acceleration is formulated as a nonlinear optimal control problem. By using direct method, it is reduced to solve the nonlinear programming problem (NLP) with constraints including equations of motion and boundary conditions. There exist a number of algorithms to solve NLP, such as SQP with direct shooting. For a constrained NLP, boundary conditions are incorporated via the use of Lagrange multipliers. However, finding appropriate initial guesses for Langrange multipliers is difficult because of the lack of a physical meaning of the variable.

In order to overcome the problem, this paper utilizes Riemannian optimization method. The set of parameter vectors satisfying the constraints are not solved in a linear space, but can be solved on a Riemannian manifold. In other words, optimization problem with constraints in linear space can be interpreted as optimization problem *without* constraints on Riemannian manifold. However, to apply the Riemannian optimization method to solve the NLP for the optimal trajectory design, concrete formulations are required. This paper shows that the set of parameter vectors satisfying the constraints of fixed final-state optimal control problem forms a Riemannian manifold. Then concrete formulations of gradient of the quadratic cost function on Riemannian manifold and retraction, which is a mapping between two points on Riemannian manifold, are derived to solve the optimization problem successively. As a result, the two-point boundary-value problem arising from the optimal control problem with fixed final-state for a nonlinear system can be solved by simpler algorithms.

Finally, this paper develops a Riemannian optimization algorithm based on the Legendre pseudospectral method to increase the accuracy of discretization of the nonlinear equations of motion for a spacecraft with low number of discrete states and inputs. As an example, the proposed optimization method is implemented to find the optimal transfer trajectory between Keplerian orbits and the validity of the proposed method is demonstrated.