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ANALYSIS OF PERIODIC AND QUASI-PERIODIC ORBITS WITH OPTIMAL FEEDBACK CONTROL

Abstract

In trajectory design for deep space exploration, dynamical structures formed by the gravitational attraction of celestial bodies are used to accomplish missions with limited fuel. Dynamical structures around the equilibria and periodic orbits in the circular restricted three-body problem have been analyzed based on dynamical systems theory. The artificial equilibria of three-body problems with external forces, such as electric propulsion and solar sails, have been also analyzed. The trajectory optimization problem with a continuous low-thrust propulsion is represented as an optimal control problem. By introducing adjoint variables , which have the same dimension with state variables, the Euler-Lagrange equation is derived as a necessary condition for the optimality. The Euler-Lagrange equation is a 12-dimensional simultaneous differential equation of state and adjoint variables. Although various techniques to solve the optimal control problem have been explored, there are only few studies of analyzing the 12-dimensional dynamical systems. In the classical LQR theory of linear systems, the 12-dimensional dynamical structures are partially connected to optimal control theory in the sense that the stable subspace in 12-dimensional space correspond to stabilizing solutions. However, a comprehensive analysis of optimal control theory from the perspective of nonlinear dynamics has not been conducted sufficiently. In this study, the Euler-Lagrange equations are considered as a 12-dimensional dynamical system, and a dynamical structure of the 12-dimensional space is revealed. In this study, dynamical systems theory is used to analyze the 12-dimensional dynamical structure around the equilibria and periodic orbits with optimal feedback control enabled by low-thrust continuous acceleration. It is shown that under optimal feedback control, L1 and L2 of the Hill three-body problem can be regarded as 12-dimensional equilibria , and there exist 12-dimensional manifolds around them. Furthermore, this study analyzes the Lyapunov family and its Quasi-Periodic Orbit (QPO) in 12-dimensional space. The extension from 6-dimensional dynamical analysis to 12-dimensional analysis based on dynamical systems theory provides deeper insights into optimal control applications for trajectory design.