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LUNAR NAVIGATION CONSTELLATION DESIGN WITH PERIODIC ORBITS IN EARTH-MOON SYSTEM BY MULTI-OBJECTIVE OPTIMIZATION

Abstract

In recent years, lunar resource exploration and crewed missions have become more active, necessitating the construction of communication and navigation infrastructure to support lunar activities. To build this infrastructure, constellations are being explored to provide communication and navigation services to users in cis-lunar space.

Previous studies on constellation design have defined the design space using Lunar orbits based on two-body problem and periodic orbits such as Halo orbits and Distant Retrograde Orbits (DRO) based on the Circular Restricted Three-Body Problem (CRTBP). These studies have framed the issue as a multi-objective optimization problem, focusing on objectives such as navigation accuracy, station keeping cost, and the number of constituent spacecraft.

In particular, there exist periodic orbits in Earth-Moon System that are effective for navigation of lunar exploration, given the fixed relative positions of the Earth, Moon, and spacecraft. Although Halo orbit and DRO Family have been studied as the design space, there are various other periodic orbits that have not yet been explored. In addition, the constellation near the Moon has a different ΔV requirement for orbit insertion depending on the transfer trajectory to the Moon and the orbit insertion method, compared to the near-Earth constellation. However, multi-objective optimization that considers the ΔV of the orbit insertion as an objective function has not been studied.

Therefore, this study aims to formulate a multi-objective optimization problem for designing a lunar navigation constellation for users in cis-lunar space and to analyze the solution space. It uses the periodic orbits in the Earth-Moon system as the design space and considers orbit insertion cost as a metric. As a method, the study first defines the design variables, which include the choice of periodic orbit and the initial phase, to uniquely determine the spacecraft's initial state. Next, objective functions such as orbit insertion cost and navigation accuracy are defined to formulate the problem as a multi-objective optimization problem. Then, the multi-objective optimization problem is solved using the Multi-objective Evolutionary Algorithm (MOEA).

For the obtained solutions, the trade-off relationship between each objective function is quantitatively represented by obtaining Pareto solutions. In addition, the study analyzes the time-series data and the design variables for each configuration of the Pareto solutions in detail. This study contributes to navigation constellation design for cis-lunar space. Additionally, considering orbit insertion cost as a metric enables discussion of the rocket launch energy and the number of launches required to build a constellation.