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VM-AC DRIVEN DYNAMIC ORBITAL RECONFIGURATION FOR COOPERATIVE ASTEROID OBSERVATION WITH MULTI-SPACECRAFT

Abstract

Asteroids, as remnants of the early formation of the solar system, typically contain abundant precious metals and rare elements, which have important scientific research and resource value. With the development of space technology, the exploration of near Earth asteroids is increasing; and the observation of target celestial bodies around asteroids is an important prerequisite for studying the evolution of the solar system and planetary defense against impact hazards. For asteroids with larger diameters, single spacecraft orbit observation entails prolonged observation periods. To address this, spacecraft clusters achieve full angle coverage of asteroid observation through a full-time observation method. The existing asteroid observation methods mainly rely on trajectory optimization based on specific models of gravitational fields, with limited adaptability and difficulty in dealing with multi-coupled environmental constraints of spacecraft clusters. Intelligent methods such as multi-agent reinforcement learning effectively reduce the dependence on global information in collaborative observation control, enabling more efficient resolution to solve the problem of spacecraft cluster trajectory planning under non-uniform gravitational fields. This study proposes a multi-spacecraft periodic observation reconfigurable orbital formation mechanism based on a Deep Reinforcement Learning (DRL). Firstly, based on the basic physical characteristics of asteroids, a composite gravitational potential energy model is constructed by integrating polyhedral gravity models and spherical harmonics functions. Then, based on the Clohessy-Wiltshire (CW) equations and distributed consensus control theory, system of dynamic equations for the spacecraft cluster in the asteroid body coordinate system is constructed. An innovatively designed Value-Matching Actor Critic (VM-AC) architecture achieves collaborative optimization through multi-objective reward functions such as fuel optimization, coverage integrity, and spacecraft cluster size, and a detailed exposition of the network training process is provided. Finally, we used the Eros as a case study to design an orbiting observation orbital configuration and conducted detailed numerical analysis with the traditional Actor Critic (AC) architecture. The effectiveness and feasibility of VM-AC in asteroid observation missions have been verified through numerical simulations, with an effective observation coverage of over 90% and a 15% increase in observation efficiency compared to traditional AC methods.