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Mission planning optimization of video satellite for ground multi-object staring imaging

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Abstract

This study investigates the emergency scheduling problem of ground multi-object staring imaging for a single video satellite. In the proposed mission scenario, the ground objects require a specified duration of staring imaging by the video satellite. The planning horizon is not long, i.e., it is usually shorter than one orbit period. A binary decision variable and the imaging order are used as the design variables, and the total observation revenue combined with the influence of the total attitude maneuvering time is regarded as the optimization objective. Based on the constraints of the observation time windows, satellite attitude adjustment time, and satellite maneuverability, a constraint satisfaction mission planning model is established for ground object staring imaging by a single video satellite. Further, a modified ant colony optimization algorithm with tabu lists (Tabu-ACO) is designed to solve this problem. The proposed algorithm can fully exploit the intelligence and local search ability of ACO. Based on full consideration of the mission characteristics, the design of the tabu lists can reduce the search range of ACO and improve the algorithm efficiency significantly. The simulation results show that the proposed algorithm outperforms the conventional algorithm in terms of optimization performance, and it can obtain satisfactory scheduling results for the mission planning problem.

Keywords: Video satellite; Staring imaging; Ant colony optimization; Tabu lists; Optimization

1. Introduction

The video satellite is a new type of earth observation satellite. Its main advantage over conventional earth observation satellites is its staring imaging ability. Achieving continuous observation of object areas over a period of time is of great significance in both military and civil applications. Staring imaging is the main working mode of the video satellite. In this mode, the satellite operates via real-time adjustment of its attitude using the attitude control system such that the optical axis of the optical sensor is always oriented toward the ground object for uninterrupted imaging. Dynamic information of object areas, which is extremely important for engineering applications, can be obtained in this manner. Moreover, for emergency operations, such as counter-terrorism and disaster relief, a large amount of image information of the objects in a certain region needs to be obtained over a certain period of time. In such cases, it is necessary to carry out mission planning so that the video satellite can achieve maximum mission success (Bai et al., 2009).

Mission planning of a single video satellite for multi-object staring imaging involves selecting, ordering, and determining the observation tasks from a group of candidate tasks to be performed under the constraints of time

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windows and satellite resources. Its objective is to maximize the mission success (He, 2004). In terms of attitude maneuverability, the video satellite belongs to the category of agile satellites, i.e., its attitude is maneuverable along the pitch, roll, and yaw axes. Compared with conventional non-agile satellites (which offer attitude maneuverability only along the roll axis), both the number and length of the visible time windows of an agile satellite with respect to an object are significantly larger. This feature improves the observation ability and flexibility of the video satellite significantly, as shown in Fig. 1. On the other hand, it may result in strong coupling or complicated conflict relationships among nearby tasks, and the observation mission sequence may no longer be fixed. Owing to these characteristics, scheduling observation tasks for agile satellites is a quite complicated task.

Previous studies on the agile satellite imaging scheduling problem have mainly focused on the solution algorithm, which leads to over-simplification of the problem. For example, the interaction among nearby tasks with overlapping time windows may be ignored. In addition, the observation attitude adjustment time, the longest continuous working time, or other constraints of the satellite may be simplified or ignored. Owing to such simplifications, the above-mentioned studies lack practical engineering significance. To overcome the drawbacks of previous studies, the present study establishes a continuous time model of single satellite mission planning by analyzing the video satellite observation process and taking various constraints into consideration. In addition, a new optimization algorithm, namely Tabu-ACO, is designed to solve the scheduling problem.

2. Research status

Existing studies have comprehensively investigated the mission planning optimization of conventional satellites. On the other hand, the task of staring imaging is based on the high attitude maneuverability of agile satellites. The mission planning optimization problem of an agile satellite is much more complicated than that of a conventional non-agile satellite, and it has been shown to be an NP-hard problem (Lemaitre et al., 2002).

Lemaitre et al. (2002), Lemaitre and Verfaillie (2007) established a constraint programming model for the scheduling problem of Pleiades, a next-generation French agile satellite. In addition, they compared four algorithms, namely greedy algorithm, dynamic programming, constraint programming, and local search algorithm. Inspired by their research, Mancel and Lopez (2003) established an integer programming model for Pleiades and adopted the column generation algorithm to solve the small-scale scheduling problem. Habet and Vasquez (2003, 2004) improved the local search algorithm proposed by Lemaitre et al. and proposed a tabu search algorithm based on the concept of uniform saturation neighborhood.

On the basis of compatibility graph theory, Gabrel et al. (1997) regarded the scheduling problem of an agile satellite as a multi-machine scheduling problem with time constrains, and they solved the model using the branch-and-bound algorithm and the longest-path algorithm. Verfaillie and Lemaitre (2001) and Verfaillie et al. (2002) regarded the agile satellite mission planning problem as a traveling salesman problem (TSP), job-shop scheduling problem (JSP), or knapsack problem. A linear model was

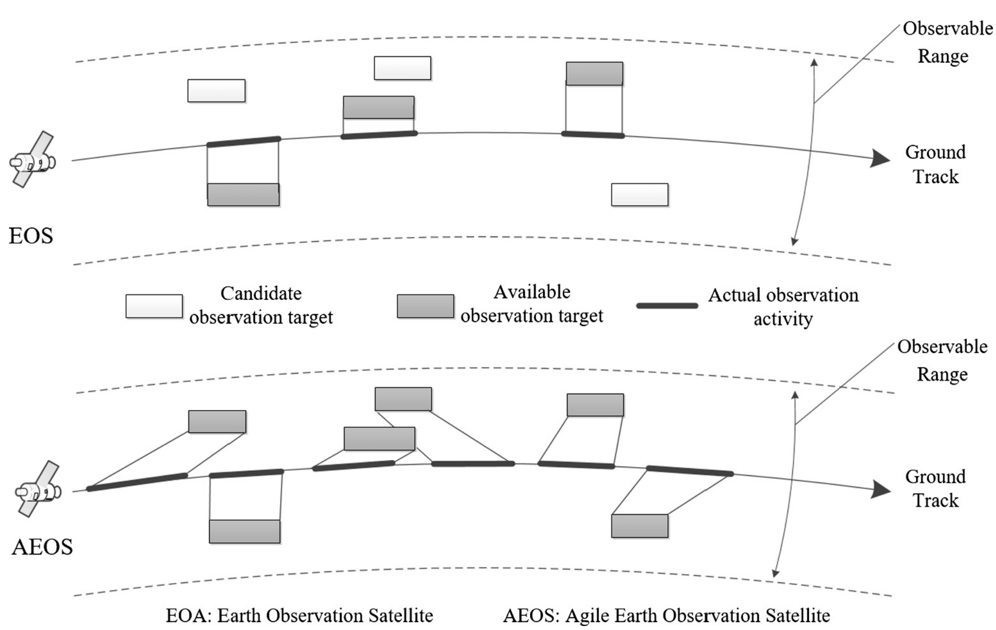

Fig. 1. Differences between imaging processes of agile and non-agile satellites.

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