An Approach of Satellite Periodic Continuous Observation Task Scheduling Based on Evolutionary Computation

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ABSTRACT

The observation task scheduling of Earth Observation Satellites (EOSs) is a complex combinatorial optimization problem. Current researches mainly deal with this problem on the assumption that one target only need to be observed once. However, with the development of remote sensing data applications, some new observation requests appear, which need EOSs take image to a target periodically. Considering the characteristic of the problem, a constraint satisfaction problem model with two objective functions is established. Furthermore, a satellite periodic continuous observation task scheduling algorithm based on multi-objective evolutionary algorithm is proposed. Finally, some experiments are implemented to validate correctness and practicability of our algorithm.

KEYWORDS

satellite periodic continuous observation; task scheduling; multi-objective optimization; evolutionary algorithm

1 INTRODUCTION

With the wide use of remote sensing data, EOSs play an important part in agriculture, industry, science detection and so on. EOSs circle on fixed orbits to acquire images of the Earth's surface (certain target), which are with respect to many constraints, such as orbit constraints, energy constraints, payload constraints and so on. Usually, satellite resources cannot meet all the observation requests in one scheduling cycle. How to determine a subset of observing tasks, which satisfies all constraints and has the optimal or near-optimal benefit has become an open issue, which is satellite observation task scheduling problem. Satellite observation task scheduling problem is a typical complex constrained multi-objective optimization problem, which has been proven to be NP-hard [1] and has been paid attention worldwide. There has been a lot of research into this problem [2-4].

Current research works are on the assumption that once a target has been imaged by satellite, the task is completed. There is no need to take image of the target anymore. Nowadays, a new type of observation request appears which need satellites take photos of a target periodically in order to get the state change trend of the target. The required observation period is called Target Observation Temporal Resolution (TOTR). Observation requests with TOTR pose new challenges to satellite task scheduling. On the one hand, if satellites take image of targets too frequently (the time span between two observations is much lower than the targets' TOTR), satellites may consume much more energy. This is a waste of valuable satellite resources. On the other hand, if the time span between two observations is much longer than targets' TOTR request, the observation data cannot indicate the state change trend of targets, so it would become valueless. Target with TOTR request has driven the objective functions and conflicts more complicated. Existing research work cannot solve this problem efficiently.

2 PROBLEM FORMULATION

We formulate the problem as a constraint satisfaction problem model EOSs observe targets on the ground when orbiting the Earth, it subjects to many constraints. In this paper, we consider the following constraints:

(a) Satellite Working Pattern Changing Constraint. For each target, satellite has to work in a certain working pattern (such as satellite attitude) to do observation. It takes time to change from one working pattern to another.

(b) Time Span Between Two Observing Constraint. Once the satellite sensor is shut down, the battery should be charged, which

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takes some time. Unless the battery has enough energy, the sensor could not work anymore.

(c) Accumulated Working Duration In One Day Constraint. The accumulated working duration of the satellite sensor in 24 hours could not be longer than some certain amount of time.

Considering of the characteristics of our problem, there are two objective functions to be optimized, which are defined as follows:

(a) Weighted Degree of Timeout (WDT)

For each target Tar_i ($i \in [1, N]$) with TOTR request $TOTR_i$, there are several satellite observations will be done to Tar_i, and the start time of these observations are $Tobs_1^i, Tobs_2^i, \cdots, Tobs_{m_i}^i$. The priority of Tar_i is Pr_i.

$$WDT = \sum_{i=1}^{N} \sum_{j=1}^{m_i-1} f(Tobs_{j+1}^i - Tobs_j^i) \cdot Pr_i \to Min \quad (1)$$

$$f(x, y)_i = \begin{cases} x - y, & if\ x - y > TOTR_i \\ 0, & else \end{cases} \quad (2)$$

(b) Degree of Energy Consumption (DEC)

The energy consuming for doing observations can be figured out and list as $Ecsm_1^i, Ecsm_2^i, \cdots, Ecsm_{m_i}^i$.

$$DEC = \sum_{i=1}^{N} \sum_{j=1}^{m_i-1} (Ecsm_{j+1}^i - Ecsm_j^i) \to Min \quad (3)$$

WDT requires satellites do observations on time and try not to exceed the deadline of all targets' TOTR request; DEC requires satellite try to save their energy when doing observations.

3 SCHEDULING ALGORITHM BASED ON EC

Some studies have indicated that common multi-satellite observation task scheduling is a typical NP-Hard problem [1]. We employ MOEA/D-PaS algorithm architecture proposed by [5] to tackle this problem.

We adopt binary encoding of the same length. For each gene site, it indicates whether one satellite observation will be done. "1" means corresponding observation will be done and "0" means the satellite will not do the observation. In our algorithm, the population is generated randomly. A multi-point crossover operator and is adopted. For observations of each satellite, there is a crossover point. In addition, single-point stochastic reverse operator is designed as mutation operator. We select a gene randomly from a chromosome, if current value of the gene is 0, we set the value = 1, vice versa. For each generation, all constraints will be handled using a heuristic repair method. If an individual violates the constraints of a satellite, the observation tasks of the satellite will be deleted based on domain heuristic knowledge[6], until all constraints are satisfied.

4 EXPERIMENT RESULTS

Computation platform in the experiment is configured as follows: Intel Core i5 2.7 GHz CPU + 8G DDR2 + Win7. Programing language is Matlab. In our algorithm, chromosome number of group is 101, the crossover rate is 0.8 and the mutation rate is 0.15. The total number of generations is 1000.

Because of no benchmark dataset in our problem, we generated the experiment data scenarios. Assuming that there are 12 satellites based on the satellite orbits database published by AGI Company in 2014, and select 16 targets randomly from world map. The experiment scenarios are shown as Table 1.

Table 1: illustrations of experiment scenarios

ID	TOTR-1h	TOTR-2h	TOTR-4h	TN	OBN
SN1	1	1	1	3	137
SN2	2	1	1	4	190
SN3	2	2	2	6	298
SN4	2	4	2	8	379
SN5	4	2	2	8	379
SN6	4	4	4	12	542

As indicated in Table 1, ID denotes the sequence number of experiment scenarios, TOTR-1h, TOTR-2h and TOTR-4h represent the number of observation targets with TOTR request being 1 hour, 2 hour and 4 hour, respectively. TN is total number of targets. OBN is the total number of observations.

The computation results are shown in Fig. 1.

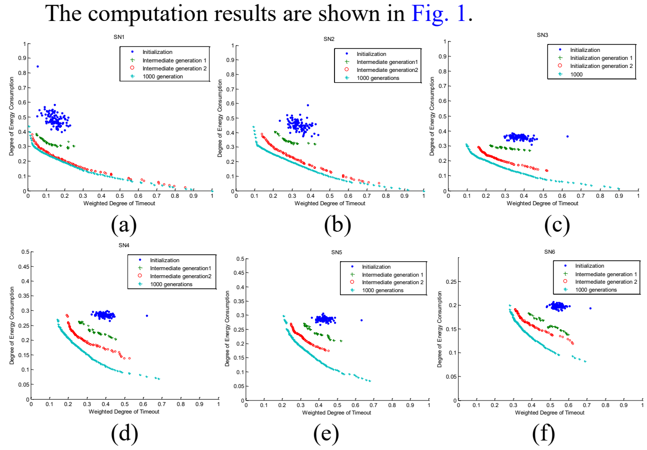

Figure 1: Computation results of our algorithm.

From Fig. 1, we can see that our algorithm can provide an optimal or near-optimal solution set to human satellite management operator.

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