Chinese Journal of Aeronautics, (2014),27(3): 678–687

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

cja@buaa.edu.cn
www.sciencedirect.com

Rescheduling of observing spacecraft using fuzzy neural network and ant colony algorithm

Li Yuqing *, Wang Rixin, Xu Minqiang

Deep Space Exploration Research Center, Harbin Institute of Technology, Harbin 150080, China

Received 7 June 2013; revised 22 September 2013; accepted 4 November 2013
Available online 2 May 2014

KEYWORDS

Ant colony algorithm;
Planning and scheduling;
Rescheduling;
Spacecraft observing;
Uncertainty

Abstract This paper aims at rescheduling of observing spacecraft imaging plans under uncertainties. Firstly, uncertainties in spacecraft observation scheduling are analyzed. Then, considering the uncertainties with fuzzy features, this paper proposes a fuzzy neural network and a hybrid rescheduling policy to deal with them. It then establishes a mathematical model and manages to solve the rescheduling problem by proposing an ant colony algorithm, which introduces an adaptive control mechanism and takes advantage of the information in an existing schedule. Finally, the above method is applied to solve the rescheduling problem of a certain type of earth-observing satellite. The computation of the example shows that the approach is feasible and effective in dealing with uncertainties in spacecraft observation scheduling. The approach designed here can be useful in solving the problem that the original schedule is contaminated by disturbances.

1. Introduction

A growing fleet of observing spacecraft uses a variety of sensing technologies for scientific, mapping, defense, and commercial activities. Hundreds of observing tasks are required to be taken every day. As the number of spacecraft and the number of observation requests grow larger and larger, scheduling these tasks is more and more difficult. Foremost is the fact that the observation scheduling is a NP-complete problem. Furthermore, there are various uncertainties in spacecraft management and operation.

Automatic planning and scheduling for spacecraft observation is the key to promoting the efficiency of spacecraft management and reducing its operation costs. Hence, it has aroused the interests of scholars in fields such as aeronautics, computer science, and operation research. Potter et al.[1] studied the scheduling problem of a linear finite deterministic model using a backtracking method, and introduced its application in the Landsat 7 mission. Lin et al.[2] and Liao et al.[3] designed the daily imaging scheduling system of ROCSAT-II using methods of tabu search, random integer programming, and Lagrange relaxation. Lemaitre et al.[4,5] studied the management of satellite resources and the observation scheduling of agile satellites. They made a further step to compare the performances of greedy algorithm, dynamic programming algorithm, and constraint programming algorithm. Wolfe et al.[6–11] studied the application of genetic algorithm to the present problem. Globu et al.[12,13] compared the performances of genetic algorithm, simulated annealing, and squeaky wheel optimization, and pointed out that stimulated annealing was

* Corresponding author. Tel.: +86 451 86418320.
E-mail address: bradley@hit.edu.cn (Y. Li).

Peer review under responsibility of Editorial Committee of CJA.

Production and hosting by Elsevier

1000-9361
http://dx.doi.org/10.1016/j.cja.2014.04.027

the best technique in their study. In recent years, particle swarm optimization[14,15] and heuristic search algorithm[16–19] were applied into this domain. Besides, many other scholars also studied the problem of multi-satellite management from different perspectives.[19–24]

However, existing research on automatic planning and scheduling for spacecraft observation mainly focuses on how to establish an initial schedule in a deterministic environment while lacks considerations for the actual operation of a satellite which is in a dynamic environment full of uncertainties such as spacecraft fault and changes in observation demands.[23,24] All of these uncertainties will affect the original schedule and cause rescheduling.

The purpose of this paper is to solve the rescheduling problem of spacecraft observation under uncertainties. What types of uncertainty are there in spacecraft observation? How do they affect the existing schedule? And how should we deal with these uncertainties? To answer these questions, the remainder of the paper is organized as follows. The next section makes a systematic analysis of uncertainties in spacecraft observation scheduling and points out that many of them have fuzzy features. Section 3 then proposes a fuzzy neural network to deal with these fuzzy uncertainties and a rescheduling policy to respond all kinds of uncertainties. Section 4 establishes a mathematical model and manages to solve this problem by using an ant colony algorithm. Finally, the above method is applied to solve the rescheduling problem of a certain type of earth-observing satellite in Section 5.

2. Uncertainties in spacecraft observation

When operating a spacecraft, there are a variety of uncertainties which demand modifications of the original schedule. In order to make efficient rescheduling policies, it is necessary to analyze the uncertainties thoroughly.

There are many ways to categorize the uncertainties. Based on the actual operating conditions, the present paper divides the uncertainties into four types according to their origins: inherent uncertainties, uncertainties aroused by changes in internal and external environments, and discrete uncertainties, as listed in Table 1.

In order to deal with various uncertainties in proper ways, it is not enough to categorize them only according to their origins. There are 20 uncertainties listed in Table 1. According to their disturbances to the system, the uncertainties are divided into three categories: abrupt disturbance, I-Type gradual disturbance, and II-Type gradual disturbance. Abrupt disturbance refers to the uncertainties with a great amplitude of changes. These uncertainties impose serious effects on the system and in most cases need a new schedule. I-Type gradual disturbance refers to the uncertainties that change frequently but mildly, which can be dealt with by periodic rescheduling. II-Type gradual disturbance bears a similarity with abrupt disturbance in their origins, but the disturbance degree of the former is not as serious. Due to its fuzzy feature, the degree of II-Type gradual disturbance needs to be evaluated according to specific conditions.

It is easier to process abrupt disturbance and I-Type gradual disturbance. They can be dealt with by using periodic and event-driven rescheduling policies. Whereas it is complicated to process II-Type gradual disturbance due to the following reasons:

(1) It is difficult to judge the responding time. If these uncertainties are not responded in time, the operating efficiency will be low and this will result in insufficient use of spacecraft resources. If these uncertainties are always responded in time, the computing load of the system will be large and the stability of the system will be affected.
(2) It is difficult to judge its degree of disturbance to the system. Firstly, there are many parameters which affect the calculation of the degree of disturbance. Secondly, it is hard to precisely decide the values of many parameters because of their fuzzy features.

Table 1 Uncertainties in spacecraft observation.

Origins		Disturbance	Degree
Inherent uncertainties	Deviation of process time	I-Type gradual disturbance	Medium
	Orbit prediction error	I-Type gradual disturbance	Medium
Uncertainties aroused by changes in internal environments	Satellite fault	Abrupt disturbance	Serious
	Satellite recovery	Abrupt disturbance	Serious
	Breakdown of some payload	Abrupt disturbance	Serious
	Recovery of some payload	Abrupt disturbance	Serious
	Partial fault of some payload	II-Type gradual disturbance	Fuzzy
	Partial recovery of some payload	II-Type gradual disturbance	Fuzzy
	Breakdown of some resource	Abrupt disturbance	Serious
	Recovery of some resource	Abrupt disturbance	Serious
	Partial fault of some resource	II-Type gradual disturbance	Fuzzy
	Partial recovery of some resource	II-Type gradual disturbance	Fuzzy
Uncertainties aroused by changes in external environments	Observation condition is not optimum	II-Type gradual disturbance	Fuzzy
	Arrival of new tasks	II-Type gradual disturbance	Fuzzy
	Task cancelation	II-Type gradual disturbance	Fuzzy
	Priority change of existing tasks	II-Type gradual disturbance	Fuzzy
	Precision change of existing tasks	II-Type gradual disturbance	Fuzzy
	Payload change of existing tasks	II-Type gradual disturbance	Fuzzy
Discrete uncertainties	Demand of attitude and orbit control	Abrupt disturbance	Serious
	Other demands of control	Abrupt disturbance	Serious