A New Problem of Resource Scheduling for Cooperative Awareness

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Abstract. In order to realize the situational awareness of the free space and strengthen the ability to perceive the random targets in free space, firstly the free space situational awareness could be realized on the foundation of cooperative surveillance. An important problem of the space surveillance system is presented and a relevant compete design project as well as a relevant object function were proposed. Besides, a new system schemes based on tabu genetic algorithm was put forward to improve the cooperative surveillance model. Through a series of theoretical derivation and some corresponding simulation experiments, it is proved that the system schemes is in possession of stronger ability for solving speed and precision, even detect and track the space object more than 1000.

Keywords: Space object · Cooperative surveillance · Resource scheduling

1 Introduction

Because of the high speed movement, large quantity and complex observation conditions of space objects, it is always a difficult problem to perceive them effectively. In order to improve the perception accuracy and timeliness, China has developed various means successively, including foundation, space-based and other resources. But there are limits to all of these [1, 2].

The ground-based system can be free from volume and power, and has high observation accuracy. However, due to the limited deployment position, there are dead corners in the observation area. In addition, it is limited by weather conditions, observation height and observation time, which leads to the restriction of the perception ability of spatial targets, especially high-orbit spatial targets. The space-based systems have the advantage of all-time, all-weather, all-day domain, can operate in the space orbit outside the earth's atmosphere, and can be effectively supplemented. Scheduling determines the efficiency of resource utilization. Space-oriented cooperative sensing resource scheduling technology is used to solve the problem of collision of detecting, tracking, imaging

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and other satellite resources, ground-based optical array, passive monitoring system and so on.

In the future, all-day, all-weather, all-orbit, wide-scale, multi-means sensing ability would make the task increasingly refined and complicated [3, 4], This makes the traditional single-equipment implementation task mode difficult to cope with, so it is urgent to develop to the direction of autonomy and synergy, that is, resource collaborative scheduling, autonomous decision-making, autonomous multi-star collaboration [5, 6] become a new trend of spatial activity collaborative perception system task mode development.

This paper discusses the problem of spatial activity co-perceived resource scheduling, which is the key to ensure the coordinated and efficient operation of equipment and improve the comprehensive performance of the system [7], It is of great significance to give full play to the advantages of space and earth sensing resources, to allocate resources effectively, and to enhance the overall efficiency of spatial goal perception and even the ability of spatial dynamic perception.

2 Resource Scheduling Modeling for Spatial Activity Collaborative Awareness

The constraints of resource scheduling problem for spatial activity collaborative sensing are more complex, the task includes point target and area target, and the area target sensing task needs to decompose the task before resource scheduling, so it needs to preprocess the observation task before task modeling. The task pre-processing stage mainly analyzes the user task requirements and standardizes the task processing and task decomposition, processes the task constraints in the task decomposition process, and prepares the data for the modeling process.

2.1 Analysis on the Resource Scheduling Problem

Considering the characteristics of multi-star sensing resource scheduling problem and combining with engineering practice, the constraints of cooperative sensing resource scheduling problem are divided into the following four categories according to the constrained objects.

Resource constraints, time constraints, state constraints, relational constraints and so on. The cooperative sensing resource scheduling problem of space-ground equipment can be used to analyze various constraints and scheduling objectives in the joint perception, abstract the basic elements such as perceived demand, scheduling target, perceived resource and so on, and establish a multi-objective optimization model.

Overall Functional Analysis and Design

Analyze multi-device collaborative sensing modeling task requirements, clarify model functions, and determine appropriate application scenarios. Wide Area Surveillance Mode: general mission programmes. The basic requirement is to make as many observations of the target as possible with minimal energy consumption. Continuous tracking mode: After discovering the task plan of the key observation object, the requirement is to realize the cumulative observation of the target as long as possible under the minimum energy consumption. Contingency mode: In the case of sudden-onset scenarios, the demand does not take into account the energy consumption to capture the target as soon as possible, and the target as much observation as possible.

Definition and Description of Input and Output Specification
Input information includes space-based sensing resources, ground-based sensing resources, measurement and control resources and digital transmission and reception resources. The output information includes the space-based system operation scenario, the Gantt chart of the observation task planning, the evolution curve of the observation task planning, and the definition description of the change map of the observation direction.

Analysis and Determination of Objective Function
As shown in Table 1, According to the requirements of wide area monitoring mode, continuous tracking mode and emergency mode, this paper establish the corresponding optimization target, then construct the concrete objective function.

Table 1. Objective function on Typical Scenarios.

Scene	Optimized goal 1	Optimized goal 2	Optimized goal 3	Optimized goal 4
Wide Area Surveillance Mode	Maximum number of observed targets	Maximum average single-objective observations	Minimum energy consumption	Star Mission Balance
Continuous tracking mode	Maximum cumulative duration of target observations	Maximum observed benefits	Minimum energy consumption	Star Mission Balance
Emergency mode	Target capture	Maximum average single-objective observations	Null	Null

In wide area monitoring mode, multiple observation devices cooperate to observe a large number of spatial targets. There are three kinds of planning targets which can be selected: the largest number of observation targets, the most number of average single target observations, and the balance of each star task. The corresponding objective functions are:

$$Max \sum x_i, i \in I \tag{1}$$

$$Max \sum (x_i \cdot times_i) / \sum x_i, i \in I \tag{2}$$

$$MinD(x_i \cdot times_i),\ i \in I \tag{3}$$

In the formula, if $x_i = 1$, the target is selected to be observed, if selected, otherwise, $x_i = 0$, $times_i$ is the times of the target to be observed, $D(\cdots)$ is the variance operator, and I is the set of observations for the target.

In the continuous tracking mode, multiple observation equipment carries on the relay continuous observation to the key target. There are three kinds of planning targets which can be selected: the longest cumulative observation time, the best observation conditions, and the balance of each star task. The corresponding objective functions are:

$$Max \sum\nolimits_r \left(\sum\nolimits_k dur_{rk}\right),\ r \in R,\ k \in O_r \tag{4}$$

$$Max \sum\nolimits_r \left(\sum\nolimits_k fit_{rk}\right),\ r \in R,\ k \in O_r \tag{5}$$

$$MinD(x_i \cdot times_i),\ i \in I \tag{6}$$

In the formula, dur_{rk} is the duration of k observation missions carried out by the r observation apparatus, fit_{rk} is the observation gains of k observation missions carried out by the r observation apparatus, $D(\cdots)$ is the variance operator, $times_i$ is the number of times the target is observed, $\mathrm{x_i} x_i$ and I is the same as above.

In emergency mode, multiple observation devices need to respond quickly and cooperate to complete the fast capture of target groups. There are two types of planning targets that can be selected: the fastest capture of all targets and the maximum number of average single target observations. The corresponding objective functions are:

$$\min \sum\nolimits_i \left(\min_n (TAs_{in})\right),\ i \in I,\ n \in TO_i \tag{7}$$

$$\max \sum (x_i * times_i) / \sum x_i,\ i \in I \tag{8}$$

In the formula, TAs_{in} is the initial time of observation missions TO_{in} for the observation target i, TO_i is the Observation sets of observation missions for the observation target i, $D(\cdots)$ is the variance operator, $times_i$ is the number of times the target is observed, x_i and I is the same as above.

Resource Scheduling Model of Spatial Activity Collaborative Awareness.

The objective function model includes four aspects: maximum number of observations, maximum number of average single-objective observations, minimum energy consumption and minimum variance of each star task.

Maximum number of observed targets:

$$Q_1 = \max\left(\sum V_i x_i\right),\ i \in I \tag{9}$$

Maximum average single-objective observations:

$$Q_2 = \max\left(\sum V_i x_i - \sum e_i x_i\right),\ i \in I \tag{10}$$

Minimum energy consumption:

$$Q_3 = \max\left(\sum V_i x_i y_i + \sum V_i x_i z_i\right), i \in I \tag{11}$$

Minimum variance of star:

$$Q_4 = \min\left[\left(\sum (V_i x_i - u)^2\right)/N\right], i \in I \tag{12}$$

In the formula, V_i is the times the observed target, if $x_i = 1$, the target is selected to be observed, otherwise, $x_i = 0$, $times_i$ is the times of the target to be observed, e_i is the cost of observation missions. if $y_i = 1$, the objective is observed in the same way as the original mission, otherwise, $y_i = \beta$, $\beta \in (0, 1)$. z_i indicates whether the target is a burst target, if $z_i = 1$,the target is non-expected one, otherwise, $z_i = 0$.

2.2 Analysis on Resource Scheduling Algorithm

In the collaborative sensing resource scheduling problem, scenario and perceptual requirements are the input of the problem. it is the purpose of resource scheduling to meet the perceptual requirements as much as possible under the consideration of various constraints, and the principle of giving priority to ensuring that high priority task requirements are served. Different solutions can be chosen according to the level and urgency of requirements, When the time requirement is high and the time requirement is not high, the requirement-oriented heuristic algorithm can be used to generate the available scheduling scheme quickly. Among the many evolutionary algorithms, genetic algorithm is one of the best tools to find satisfactory solutions to combinatorial optimization problems. Some scholars have applied genetic algorithm to solve the related problems of observation resource scheduling. Although genetic algorithm has the advantages of parallel search and high search efficiency, it also has the disadvantages of weak local search ability and easy precocity.

As a complex combinatorial optimization problem with time window constraints, the genetic algorithm is a stochastic search algorithm, which needs to be searched step by step in the whole solution space. The number of decision variables of the multi-star resource scheduling problem is large, and the corresponding solution space is also naturally huge, so the time cost of the algorithm will be large.

Based on the factors of satellite resource, ground resource and task requirement, this paper proposes an optimal solution method of collaborative sensing resource scheduling based on tabu genetic algorithm. The basic idea of tabu genetic algorithm is to use the evolutionary function of genetic algorithm to make the search quickly concentrate around the better solution, and then use the tabu search method to further search the optimal solution in a small range.

By combining the advantages of genetic algorithm ideas and tabu search methods, we can effectively use global information and the information obtained in the search process to search repeatedly in the neighborhood and move quickly and effectively in the direction of the optimal solution, so as to effectively overcome the local optimization and achieve the purpose of improving the solution effect and search efficiency. The concrete realization process is mainly divided into three stages: preliminary optimization, taboo processing and termination judgment.

Step 1: Initial optimization.
Input the original data and the required parameters, form the initial population, calculate the fitness value and make the preliminary optimization.
Step 2: Taboo handling.
Select based on elite selection, cross and mutate based on tabu search, and update tabu table.
Step 3: Termination judgement.
Determine whether the tabu algorithm termination condition is satisfied, If satisfied, jump out of taboo optimization, and genetic optimization operation. if not satisfied, continue to taboo operation, until the survival probability of the largest chromosome.

3 Analysis of Examples Based on Simulation Verification

3.1 System Testing and Validation

Based on the aforementioned cooperative sensing resource scheduling algorithm, Based on the idea of modularity, a software module of collaborative sensing resource scheduling based on Tabu Genetic Algorithm is developed, and related test applications are carried out, The typical interface of the software module is shown in Fig. 1. Figure 2 shows a preliminary optimization scheme for resource scheduling of a sensing task: The software plans space—ground resource allocation plans based on a programme of collaborative sensing tasks for space activities, Generating work task sequences and time windows for various available resources; The change curve of attitude angle is a guarantee requirement for the platform to support the smooth implementation of space-based detection, tracking, imaging load work plan and measurement and control data transmission plan, The software system can respond quickly to the task requirement.

Fig. 1. Design of scheduling Software Interface Based on Cooperative surveillance

3.2 Comparative Analysis

In order to test the advantages of the system introduced in this paper, a comparative analysis is carried out based on the application background of the joint perception task of space and ground, and to obtain the maximum task income as the objective function.

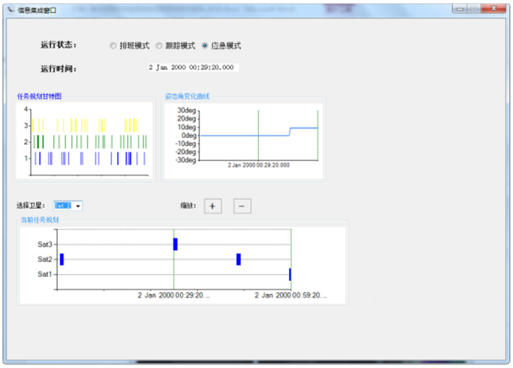

Fig. 2. Preliminary result of scheduling on Cooperative surveillance

objective function: Maximum cumulative gain

$$\max \sum\nolimits_r \left(\sum\nolimits_k fit_{rk} \right), r \in R, k \in o_r \tag{13}$$

In the formula: fit_{rk} is the benefits of k observation missions carried out by the observation subjects, R is the collection of observation subjects, o_r is the collection of observation missions from observation subject r. In the background of satellite and ground station joint sensing mission planning, the simulation calculation of observation task scheduling is now in progress, in which Three algorithms are applied to optimize the solution based on objective function.

In order to reduce the influence of contingency, each algorithm runs independently for 30 times when solving, recording the solution it finds, the number of times it finds the optimal solution, the number of rounds to find the optimal solution, and the average running time. The results are shown in Table 2, Fig. 3 shows the three algorithms running at one time.

Table 2. Calculation Results Characteristics

Algorithm	Objective function			Number of optimal solutions	Optimal rounds			Mean time (s)
	Worst	Best	Avg		Min	Max	Avg	
Priority heuristic	7990	7990	7990	0	0	0	0	1.1812
tabu genetic	8075	8984	8772	23	110	130	125.3	189.135
Ant colony hybrid	8053	8984	8922	28	81	98	88.7	173.413

As we can see, Under the compound optimization objective function, The cooperative sensing resource scheduling system proposed in this paper has faster convergence speed and stronger ability to find the optimal solution.

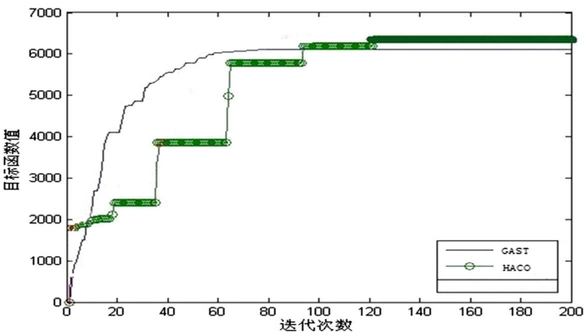

Fig. 3. Comparison of processes based on different algorithm

4 Conclusion

In this paper, the requirement, current problems and countermeasures of resource scheduling system for spatial activity cooperative sensing are expounded in detail. Taking the task income as the specific measurement value, it proves that the resource scheduling system has obvious advantages in the speed of scheduling optimization, the speed of algorithm convergence, the accuracy of solution, and so on.

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