DYNAMIC MISSION PLANNING TECHNOLOGY OF REMOTE SENSING SATELLITE FOR DISASTER SURVEILLANCE

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ABSTRACT:

The mission planning problem of remote sensing satellites for emergency missions is investigated. A dynamic mission planning technology is introduced to solve the problem. For generating the new plan as soon as rapidly, the new emergency missions are dynamically inserted to the original plan through adjusting the original plan partially. The three strategies of dynamically adjusting original plan are proposed firstly, including task-first strategy, change-least strategy, and Imaging time-earliest strategy. A kind of rule-based heuristics search algorithm is proposed, which is composed of three insertion processes, namely direct insertion, iterative insertion, and substitutional insertion. In order to generate the reasonable imaging plan, two kinds of heuristic rules are designed specially. At last, a simulation is presented and the results show that the effectiveness of the algorithm.

1. INTRODUCTION

Recently, the disasters, such as earthquake, flood, etc, take place frequently, so the disaster surveillance based on the remote sensing satellite is becoming the focus of research. When the disaster breaks out, the basic establishments of disaster area, such as traffic, power, and communications are often interrupted. The information of disaster can't be obtained through the traditional approach, such as phone. The remote sensing airplane can't cruise because of vile weather to imaging the disaster area, which makes the succor difficultly. During this situation, remote sensing satellites are becoming the one and only disaster surveillance instrument, through which the situation of disaster can be obtained in time.

This paper analyses the application of remote sensing satellite in disaster surveillance, and corresponding mission planning strategies are summarized. A kind of dynamic mission planning algorithm is proposed for disaster surveillance, which make the tradeoff between efficiency and optimization.

2. DYNAMIC MISSION PLANNING FOR DISASTER CURVILLANCE

2.1 Putting forward the question

For remote sensing satellites, the imaging plan, namely, the sequence of imaging activities of satellite for the future, need to be planned in the ground in advance, and then the plan is transmitted to satellite by way of appreciate uplink for execution.

Mission planning for remote sensing satellites is to generate the imaging plan, and it is an optimization process, which objective is to decide which imaging mission will be scheduled according to the optimization objective, and allocate imaging resources and time slots for those scheduled missions.[1] The problem of mission planning for remote sensing satellites is difficult to solve because there are too many imaging missions to be scheduled for the numbered satellites and there are many restraints on satellite imaging. Too many imaging missions make the space of resolution of mission planning problem is too large to search. Many restraints imply that there are many qualifications to be checked during the search process. Consequently, it will cost much time to find the best imaging plan for remote sensing satellites.

When some emergencies, such as forest fire, flood, earthquake, etc, take place, the original imaging plan must be adjusted and transmitted rapidly to acquire the remote sensing data for these disasters. Obviously, it is unfeasible to plan the entire missions of remote sensing satellites over again when emergency happens, because it will cost too much time to acquire the remote sensing data rapidly. So, the new mission planning technology, dynamic mission planning technology, is proposed and developed to solve the mission planning problem for emergency missions.

The new emergency mission, such as disaster, is few after at all. So, different from the traditional mission planning technology, the dynamic mission planning technology concentrates attention on the few emergency missions, not all the missions. The dynamic mission planning technology plans the new emergency missions based on the original plan. For generating the new plan as soon as rapidly, the new emergency missions are dynamically inserted to the original plan through adjusting the original plan partially.

2.2 Dynamic mission planning strategies

In order to imaging the disaster area in time, and adjusting the original plan optimally, three dynamic adjusting strategies are given here.

Task-first strategy: according to this strategy, the priority of disaster surveillance target is higher than the targets in the original plan. When the disaster surveillance target conflict with the other targets, the other targets should be adjusted to

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insure the disaster surveillance target is scheduled.

Change-least strategy: According to this strategy, the change between the original plan and new plan should be least as possible. When there are several new plans schedule the disaster surveillance targets, we should select the plan with least changes. The degree of changing can be measured by the amount of changed targets, including adjusted targets and canceled targets. This strategy can be used in two steps. Firstly, select the plan with less canceled targets. Secondly, select the plan with less adjusted targets.

Imaging time-earliest strategy: According to this strategy, the disaster surveillance targets should be scheduled as soon as possible. For one surveillance target, if there are many imaging time windows, we should select the time window with early imaging time to obtain the image of disaster area as soon as possible.

The above three strategies can be combined according to the reality. Normally, we should apply the three strategies in order.

2.3 Dynamic mission planning algorithm

Mission planning problem of multi-satellites for disaster surveillance is a dynamic mission planning problem, which required to be solved quickly. Because the dynamic mission planning is based on the original plan, this paper designs a kind of task adjusting algorithm based on the task insertion, which inserts the disaster targets into the original plan according the imaging time to avoid adjusting the original plan entirely.

This algorithm is made up of task-insert-directly process, task-insert-iteratively process, and task-insert-substitutionally process. Task-insert-directly process inserts the task into the original plan without influencing the order of the original tasks, which process can insure the stability of the plan. Task-insert-iteratively process inserts the task into the original plan without deleting the original tasks, which process is likely to make the original task's resource and time window changed. Task-insert-substitutionally process inserts the task into the original plan with removing the corresponding original task, which process can't insure the stability of the plan. When inserting the new tasks, the above three processes should be applied in order. The flow of dynamic adjusting algorithm is shown in Figure 1.

(1) task-insert-directly process
Without changing the task's resource and time window in original plan, task-insert-directly process selects the highest priority task in turn firstly, then calculates and estimates whether the imaging constraints are satisfied or not. If the constraints are satisfied, the task is inserted into the corresponding imaging sequence. When inserting the new task, we should select the time windows which have no conflict with the others.

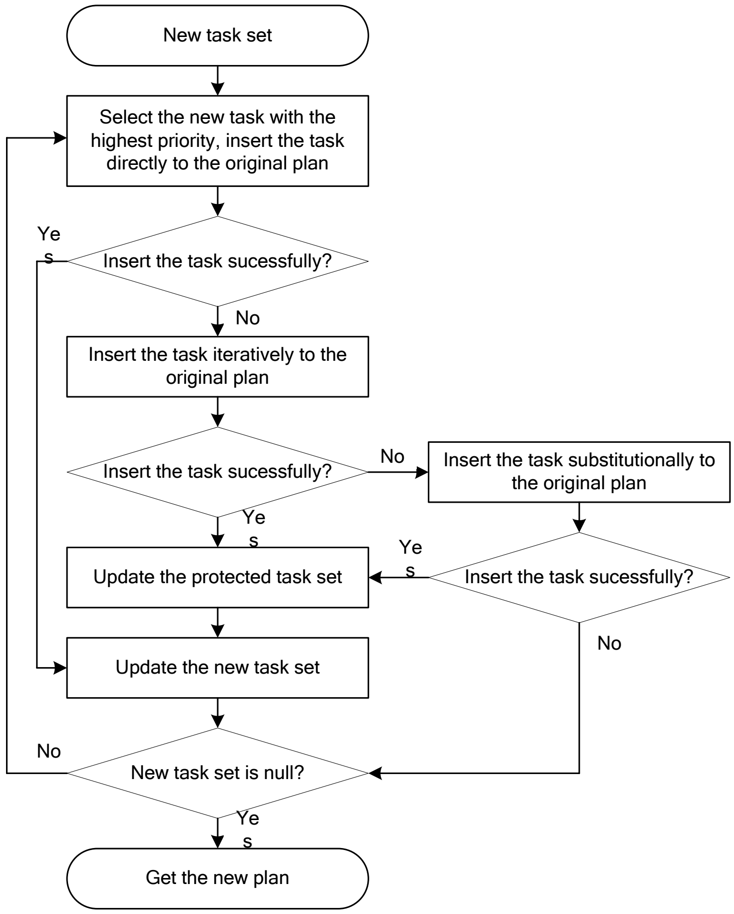

Figure 1 Flow of dynamic adjusting algorithm

(2) task-insert-iteratively process
Task-insert-iteratively process is the core of dynamic mission planning algorithm. This process is based on the iterative repair approach. Given the new task i, if it can be inserted into the original plan through iterative search without deleting the original task, the new plan is accepted. Or else, the original plan is reserved and the new task is kept unarranged.

When searching iteratively, in order to insert the new task into a feasible time window, some original tasks need to be canceled temporarily. As Figure 2 shows, if the new task i is inserted into the time window, the tasks j and k, or the tasks l and k should be canceled. So the task set $\{j,k\}$ and $\{k,l\}$ is defined as the conflict of i, and $\{\{j,k\},\{k,l\}\}$ is defined as the conflict set of i in time window $[est_i, lft_i]$ of resource r. For the mission planning problem of multiple satellites, a target can be visited by multiple satellites in different time windows. So the conflict set of i includes all the conflicts in all visited time windows.

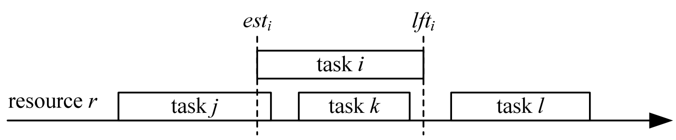

Figure 2 the conflict set of task i

Declare some variables as follows:

$Taskset(tw)$: denotes the entire feasible task set in time window tw of some a satellite.

$TWset_i$: denotes the entire feasible time windows of task i in all the satellites.

$Conflictset_i$: denotes the conflict set of i .

$Conflictset_i^j$: denotes the conflict j in the conflict set of i .

Firstly, the requirement of time window is proposed, which describes the degree of requirement of time window occupied by tasks. Its calculation formula is:

$$req(tw) = \sum_{i \in Taskset(tw)} \frac{w_i}{|TWset_i|}$$

According to the above formula, the requirement of time window is not only relating to the priority of tasks in the time window, but also relating to the amount of time windows of task. After denoting the requirement of time window, the freedom of task is given as the reciprocal of the minimal requirement in all time windows of the task. Less the minimal requirement of time window is, larger the freedom of task is, and the task is more possible to be arranged.

$$flex_i = \min_{tw \in TWset_i} 1/req(tw)$$

Because the conflict involves multi-tasks, there are multi-tasks to be canceled for inserting a new task. The difficulty of Arranging all the tasks involved in the conflict is decided by the task with least freedom in the conflict, so the freedom of conflict is denoted as follows:

$$flex(Conflict_i^j) = \min_{k \in Conflict_i^j} flex_k$$

Based on the freedom of conflict, two heuristic rules are designed to cancel the original tasks as follows:

- Max-freedom-based heuristic rule

While designing the heuristic rule, the usual goal is to cancel the task with more feasible time windows. It is easy to calculate the amount of feasible time windows of task. This index can describe the difficulty of inserting the task, but it can’t describe the requirement of this feasible time windows. If some a task has more feasible time windows, but these time windows are feasible for the other tasks, it is possible that the task can’t be arranged again after it is canceled. So the Max-freedom-based heuristic rule is proposed based on the freedom of conflict as follows:

$$Retracttask_i = Conflict_i^j : flex\left(Conflict_i^j\right) \geq flex\left(Conflict_i^k\right), \quad \forall k \neq j$$

While inserting the new task, the original task with max-freedom in conflict set is selected.

- Proportion-freedom-based heuristic rule

While selecting the task to be canceled, firstly calculating the proportion of freedom of every conflict to the sum of freedom of all conflict, and then selecting the proportion as the probability of canceling the task. Proportion-freedom-based heuristic rule is shown as follows:

$$Prob(Retracttask_i = Conflict_i^j) = flex(Conflict_i^j) \div \left(\sum_{1 \leq k \leq |Conflictset_i|} flex(Conflict_i^k) \right)$$

According to the Proportion-freedom-based heuristic rule, the task with max-freedom is possible to be canceled most, while the task with min-freedom is possible to be canceled least. The profit of this rule is that all the tasks in the conflict are possible to be canceled, which avoids the search into the local extremum.

(3) task-insert-substitutionally process

Task-insert-directly process and task-insert-iteratively process both insert the new task into the original plan without deleting the original tasks. But in many situations, all the new tasks can’t be inserted only using the above two rules. It is necessary to delete the original task to insert the new task, which is task-insert-substitutionally process.

3. SIMULATION

3.1 Simulation data

For validating the effect of the dynamic adjusting algorithm, some instances of the problem are constructed, and the initiate solutions are given. Constructing instances is related with the amount of satellites, length of time windows, and distribution of different targets. Through combining these three factors, six instances are designed as follows:

Table Ⅰ the characters of initial instances

	TP1	TP2	TP3	TP4	TP5	TP6
Amount of satellites	2	2	4	4	7	7
Length of time windows	[10,15]	[20,30]	[45,60]	[10,15]	[20,30]	[45,60]
Distribution of targets	gather	scatter	gather	scatter	gather	scatter

The initial plans of all instances are gotten by using the greed search algorithm. The profits of new task are more than the original tasks, which values are supposed to be at [7, 10]. The proportion of new tasks to all the tasks is set as 5%, 10%, and 20% separately. The length of time windows of new tasks is same as initial instances, and these time windows scatter.

Finally, the characters of these instances are shown as follows:

Table Ⅱ the parameters of instances of dynamic mission planning problem

Serial number	Instance name	Initial profits	Amount of New tasks	Serial number	Instance name	Initial profits	Amount of New tasks
1	TP1–1	569	10	10	TP4–1	1157	10
2	TP1–2	569	20	11	TP4–2	1157	20
3	TP1–3	569	40	12	TP4–3	1157	40
4	TP2–1	628	10	13	TP5–1	1477	10
5	TP2–2	628	20	14	TP5–2	1477	20
6	TP2–3	628	40	15	TP5–3	1477	40
7	TP3–1	1147	10	16	TP6–1	1477	10
8	TP3–2	1147	20	17	TP6–2	1477	20
9	TP3–3	1147	40	18	TP6–3	1477	40

According to the strategies, three evaluation indexes are denoted as follows:

E_1 : Profits of the new plan.

E_2 : Change ratio of the plan, which is the amount ratio of the tasks which is not arranged in the original time window in new plan to the tasks in original plan.

E_3 : Calculating time of algorithm.

3.2 Results

According to the applied rule, dynamic adjusting algorithm is divided into the algorithm based on max-freedom heuristic rule (MF_DITHA) and the algorithm based on Proportion-freedom heuristic rule (FP_DITHA), and the depth of iterative searching is set as 10. Applying the two algorithms to solve the every instance for 100 times, and averaging the values of all solutions. The results are shown as follows:

Table Ⅲ the results calculated by the two algorithms

instances	MF_DITHA			FP_DITHA		
	E1	E2	E3	E1	E2	E3
TP1–1	525.2	6.8%	1.9	519.3	5.2%	1.2
TP1–2	566.7	10.1%	3.2	557.1	9.6%	1.7
TP1–3	599.8	13.4%	4.5	586.9	12.5%	3.2
TP2–1	545.4	7.1%	2.0	531.2	5.6%	1.4
TP2–2	588.3	10.4%	3.4	574.7	10.0%	1.9
TP2–3	619.0	14.3%	5.1	605.3	12.8%	3.8
TP3–1	999.8	10.7%	2.5	990.6	9.4%	1.8
TP3–2	1056.7	17.9%	3.9	1038.9	15.2%	2.4
TP3–3	1103.8	24.6%	6.8	1093.6	19.3%	4.5
TP4–1	1008.3	11.4%	2.7	992.7	10.8%	1.9
TP4–2	1079.0	19.6%	4.1	1068.3	17.4%	2.7
TP4–3	1129.8	25.8%	7.0	1117.6	20.5%	5.1
TP5–1	1555.4	12.2%	3.2	1549.2	11.1%	2.2
TP5–2	1631.3	19.9%	4.7	1624.7	17.6%	3.1
TP5–3	1709.0	26.4%	8.1	1695.3	21.3%	6.2
TP6–1	1542.8	12.3%	3.3	1536.9	11.5%	2.3
TP6–2	1635.4	19.4%	4.6	1627.2	17.8%	3.2
TP6–3	1708.3	26.9%	8.2	1694.7	21.7%	6.4

From the above results, we can see that the profits of MF_DITHA are better than the FP_DITHA, and the change ration of FP_DITHA are less than the MF_DITHA.

4 CONCLUSIONS

The disaster surveillance based on the remote sensing satellite is the focus of current research. This paper regards the disaster surveillance targets as a kind of emergency targets, and proposed the dynamic mission planning algorithm, which can adjust the original plan quickly and optimally through different task inserting process and heuristic rules.

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