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Article

Evaluation Model of Remote Sensing Satellites Cooperative Observation Capability

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Abstract: This paper proposed a new evaluation model based on analytic hierarchy process to quantitatively evaluate the capability of multi-satellite cooperative remote sensing observation. The analytic hierarchical process model is a combination of qualitative and quantitative analysis of systematic decision analysis method. According to the objective of the remote sensing cooperative observation mission, we decompose the complex problem into several levels and a number of factors, compare and calculate various factors in pairs, and obtain the combination weights of different schemes. The model can be used to evaluate the observation capability of resource satellites. Taking the optical remote sensing satellites such as China's resource satellite series and GF-4 as examples, this paper verifies and evaluates the model for three typical tasks: point target observation, regional target observation and moving target continuous observation. The results show that the model can provide quantitative reference and model support for comprehensive evaluation of the collaborative observation capability of remote sensing satellites.

Keywords: remote sensing; collaborative application; observation capability; evaluation

1. Introduction

The application of remote sensing satellites can realize global observation with full time, wide range and high reliability, and it is an important means to obtain information of global hotspots and large-scale regional surveys. Remote sensing satellites with decentralized management usually provide emergency high-frequency observation services in the form of satellite maneuvering orbit or camera tilting. However, its economic cost is extremely high, the orbit cannot fully meet the requirements of global emergency support. The comprehensive utilization of multiple remote sensing satellites is of great significance to the support of data in emergency situations.

The performance evaluation of remote sensing satellites includes task analysis1, index system construction, evaluation method selection and so on. There are few literatures on the mission effectiveness evaluation of remote sensing satellites, which mainly focus on mission analysis, index system construction or comprehensive evaluation method research2. Moreover, the comprehensive evaluation research of the remote sensing satellite system is not sufficient3, but the evaluation of the whole space equipment system or satellite equipment system is mostly carried out4. In recent years, the remote sensing satellite systems effectiveness evaluation research has been also started from the equipment system5-7. On the whole evaluation of remote sensing satellite system in which the role of the concrete to the remote sensing satellite mission effectiveness evaluation system, the combination of analytic hierarchy process (AHP) and the ADC efficiency model

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is more widely used in the information system effectiveness evaluation8-10. AHP is essentially an expert evaluation method, which deals with various decision-making factors in qualitative and quantitative ways, and has the advantages of being systematic, flexible and concise. It has been widely valued and applied in the field of complex system evaluation.

The basic principle of AHP is based on the nature of the problem and different factors to achieve the goal of decomposition problems 11, and to carry out hierarchical clustering combination according to the relationship between the factors and the subordinate relations, forming a hierarchical and orderly hierarchical structure model. Then, the model gives a quantitative expression on the relative importance of factors at each level on the basis of people's judgment of the objective reality, and uses mathematical methods to determine relative importance weight order of all the factors at each level 12. Finally, by comprehensively calculating the weight of relative importance of factors at various levels, we can obtain the importance weight of the lowest level factors to the highest level, or rank the order of advantages and disadvantages, as the basis for the evaluation and selection of the scheme. This method can be used to quantitatively evaluate the system performance and mission effectiveness, and to compare and analyze a variety of system schemes, which is very suitable to for the evaluation of satellite cooperative capability. This paper using the proposed method to make a quantitative analysis on the cooperative application of multi-satellites to improve remote sensing observation capability.

2. Evaluation model

In order to scientifically the satellite resources quantitative assessment on the degree of remote sensing observation ability to ascend, the project is to build a remote sensing observation ability evaluation model. The index system of remote sensing observation ability evaluation and the formula of remote sensing observation capacity are included, which are used to quantitatively evaluate the remote sensing observation ability. The actual support effect of synergistic satellite resources is evaluated by the change of remote sensing observation ability under the condition of whether or not collaborative satellite resources are available. Through the quantitative comparison and analysis of the overall observation capability of resource satellites and the coordinated overall observation capability of satellites, the actual support effect of the coordinated satellite resources to remote sensing observation is evaluated.

On the basis of the hierarchical analysis model that combines qualitative and quantitative analysis, we build a remote sensing observation ability evaluation model, which decomposes complex problems into several levels and a number of factors, and compares and calculates each factor in pairs, thus obtaining the combination weights of different schemes.

Using the AHP to construct remote sensing observation process capability evaluation model are as follows：

2.1. Building a hierarchical evaluation model

Focusing on the overall goal of constructing the remote sensing observation capability evaluation model, and following the principle of independence of the same level of indicators, the remote sensing observation capability is decomposed into three second-level evaluation indices, namely point target observation capability, regional target observation capability and moving target observation capability. Then, each second-level evaluation index is further decomposed and refined into third-level indicators. There are interrelated influences and subordination relations among different index levels, and the evaluation values of lower-level indicators are aggregated into the evaluation values of upper-level indicators according to their weights, producing the total evaluation results of remote sensing collaborative observation ability, as shown in Figure 1.

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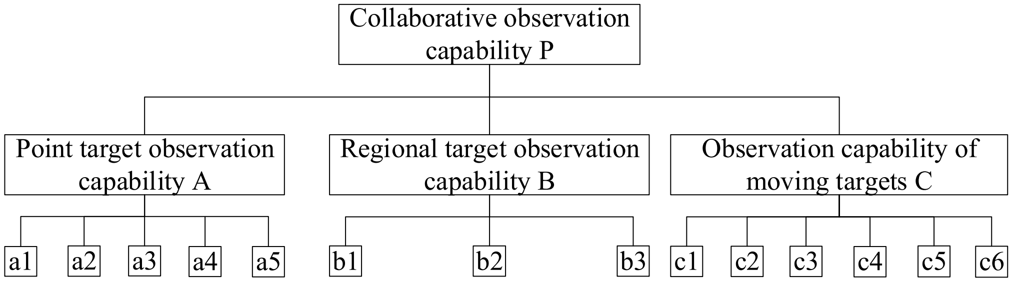

Figure 1. Remote sensing observation ability evaluation index system

Label	Description
a1	Total number of weekly target visits
a2	Maximum revisiting interval
a3	Minimum revisiting interval
a4	Average revisiting interval
a5	Weekly target visits
b1	Observation frequency of the full coverage of the region
b2	Total time of the full coverage of the region
b3	Total time of the target observation
c1	Total number of target visits
c2	Maximum revisit interval
c3	Minimum revisit interval
c4	Average revisit interval
c5	Total duration of target observation
c6	Overall observation capability

Point target observation capability: refers to the observation capability of the point target. The measurement indexes mainly include the total number of weekly target visits, the maximum revisiting interval, the minimum revisiting interval, the average revisiting interval and the total number of weekly target observations. The total number of weekly target visits represents the total number of times the satellite resource set can visit the target in a week. The maximum revisit time interval represents the maximum time interval of two consecutive access point targets; The minimum revisit time interval represents the minimum time interval of two consecutive access point targets; The average revisit time interval represents the average time interval of two consecutive visit points; The total number of weekly target observations indicates the number of opportunities to access the point target during the week.

Regional target observation capability: refers to the observation capability of the opposite target. The measurement indexes mainly include the observation frequency of the full coverage of the region, the total time of the full coverage of the region and the total time of the target observation. The observation frequency of regional total coverage represents the observation visit frequency needed to achieve the global coverage of the opposite object. The total coverage time of the region is expressed as the time spent from the beginning time of the first visit to the planar target to the end time of the last visit to the planar target when the full coverage of the region is completed. The total time of target observation is expressed as the sum of detection time of each visit to the regional target in the process of achieving full coverage of the region.

Observation capability of moving targets: it refers to the accompanying observation capability of moving targets. The measurement indexes mainly include the total number of target visits, the maximum revisit interval, the minimum revisit interval, the average revisit interval, the total duration of target observation and the overall observation capability. The total number of target visits refers to the number of times that the target can be accessed during the whole movement of the target. The maximum revisit time interval represents the maximum time interval of two consecutive access point targets. The minimum revisit time interval represents the minimum time interval of two consecutive access point targets. The average revisit time interval represents the average time interval of two consecutive visit points. The total time of target observation is expressed as the sum of detection time of each visit to the moving target in the whole process of target movement. Whole-course observation capability indicates the ability to conduct whole-course observation on the target.

The remote sensing observation capability assessment model constructed by AHP is extensible, and new evaluation indexes can be added at each level as needed. For example, when there are satellites with staring observation ability, the evaluation index of the "staring observation objective" can be added.

2.2. Determine index weight

(a) Construct the priority relation judgment matrix

The priority relationship judgment matrix reflects the priority relationship between two indicator factors related to a certain element in the previous layer at this level. It is assumed that element B in the previous level is related to elements a_i and a_j in the next level. When the elements a_i and a_j are compared with the elements B in terms of E, there are expressions such as "... than... much more important" fuzzy relationship. In order to determine the importance of element a_i relative to a_j, it is necessary to establish a fuzzy judgment scale expressed by the Numbers 0.1 ~ 0.9, as shown in Table 1.

Table 1. Relative importance scale table

r_{ij}	define	instructions
0.5	As important	Elements compared to the elements of a_i and a_j, are equally important
0.6	A little important	Elements compared to the elements of a_i and a_j,A little important
0.7	Obviously important	Elements compared to the elements of a_i and a_j, are obviously important
0.8	Much more important	Elements compared to the elements of a_i and a_j, are much more important
0.9	Extremely important	Elements compared to the elements of a_i and a_j, are extremely important
0.1，0.2，0.3，0.4	Inverse comparison	If the element a_i is compared with element a_j to get r_{ij}. the comparison between element a_j and element a_i is r_{ij}=1-r_{ij}

According to the contents in the table above, the relative importance of each index in the same level relative to its upper level index is judged by using the expert investigation method, including: for primary index "remote sensing observation ability", three secondary indicators "point target observation ability", "regional target observation ability" and "moving target observation ability between the relative importance of judgment. For the second-level indicator "point target observation capability", five third-level indicators "total number of weekly target visits", "maximum revisit time interval", "minimum revisit time interval", "average revisit time interval" and "total weekly target observation time" are judged as their relative importance. For the second-level indicator "regional target observation capability", the relative importance of the three third-level indicators "regional total coverage observation times", "regional total coverage time" and "total target observation time" is judged. For the second-level indicator "moving target observation capability", the relative importance of the six third-level indicators "total number of target visits", "maximum revisit interval", "minimum revisit interval", "average revisit interval", "total target observation duration" and "overall observation capability" was judged.

The judgment matrix composed of expert judgment values is expressed as:

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$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & & & \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

Type for index factors relative to the importance of the factors which a relative to the importance of U as the index factors, among them, i = 1, 2, 3,... , n. e = 1, 2, 3... , m. The value on the main diagonal represents the importance of each factor in its own self-comparison, so its value is 0.5.

(b) Construct the fuzzy consistent judgment matrix

Due to the complexity of the research problems and the difference of different experts" understanding of the importance of the same index factor, the final judgment matrix is often inconsistent. Therefore, it is necessary to transform the above obtained fuzzy complementary matrix into fuzzy uniform matrix. The steps of constructing the fuzzy consistency matrix are as follows:

Step 1: sum the matrix $A = (a_{ij})_{n\times n}$ by rows, that is $r_i = \sum_{m=1}^{n} a_{im}$, i=1,2... n

Step 2: perform the following mathematical transformation: $r_{ij} = \frac{r_i - r_j}{2(n-1)} + 0.5$

Through the above two steps can get fuzzy consistent matrix $R = (r_{ij})_{n\times n}$.

(c) Computing weight set

Step 1: The weight value at the level of each factor is calculated using the normalized method. The calculation steps are as follows:

$$e_{ij} = \frac{a_{ij}}{a_{ji}} \quad \mathrm{i, j} = 1, 2, \ldots \mathrm{n} \tag{2}$$

Step 2: find the initial weight vector $A^{(0)}$

$$A^{(0)} = (a_1, a_2, \ldots, a_n)^T = \left(\frac{\sum_{j=1}^{n} e_{1j}}{\sum_{i=1}^{n}\sum_{j=1}^{n} e_{ij}}, \frac{\sum_{j=1}^{n} e_{2j}}{\sum_{i=1}^{n}\sum_{j=1}^{n} e_{ij}}, \ldots, \frac{\sum_{j=1}^{n} e_{nj}}{\sum_{i=1}^{n}\sum_{j=1}^{n} e_{ij}}\right)^T \tag{3}$$

Step 3: take $A^{(0)}$ as the initial value of iteration V_0, use the eigenvalue method to optimize the weight vector, take $V_0 = (v_{01}, v_{02}, \ldots, v_{0n})^T$ as the initial value of iteration, use iteration $V_{k+1} = EV_k$ to find V_{k+1}, and find its infinite norm $\|V_{k+1}\|_\infty$.

If $\|V_{k+1}\| - \|V_k\| < \varepsilon$, then $\|V_{k+1}\|_\infty$ is the maximum eigenvalue and the iteration ends. The vector V_{k+1} obtained by the normalization of I is taken as the weight vector ${V_{k+1}}^{(norm)}$ after optimization, namely

$$A = V_{k+1}^{norm} = \left(\frac{V_{k+1,1}}{\sum_{i=1}^{n} V_{k+1,i}}, \frac{V_{k+1,2}}{\sum_{i=1}^{n} V_{k+1,i}}, \mathrm{L}, \frac{V_{k+1,n}}{\sum_{i=1}^{n} V_{k+1,i}}\right)^T \tag{3}$$

Otherwise, take $V_k = \frac{V_{k+1}}{\|V_{k+1}\|_\infty}$ as the initial value of the new iteration, and carry out iterative optimization calculation again.

Based on the above methods, the weight coefficients of each layer in the remote sensing observation capability evaluation index system are calculated. According to this method, users can adjust the weight coefficients of each layer at any time.

Firstly, through discussion with experts, the fuzzy judgment matrix of indicators in each layer of the remote sensing observation capability evaluation index system is determined. The specific situation is as follows.

F_p is used to judge the relative importance of three secondary indicators "point target observation capability A", "regional target observation capability B" and "moving target observation capability C". The pairwise comparison among the three indicators forms a 3×3 matrix, and the meanings of each element in the matrix are shown in Table 2.

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Table 2. Judgment matrix

A/A Relative importance	A/B Relative importance	A/C Relative importance
B/A Relative importance	B/B Relative importance	B/C Relative importance
C/A Relative importance	C/B Relative importance	C/C Relative importance

According to the experience and discussion of experts, the specific value of F_p is as follows:

$$F_p = \begin{bmatrix} 0.5 & 0.6 & 0.7 \\ 0.4 & 0.5 & 0.6 \\ 0.3 & 0.4 & 0.5 \end{bmatrix} \tag{4}$$

P_A stand for the five belongs to the "three indicators point target observation ability", "week visit to the total number of a1", "maximum revisit time interval a2", "minimum revisit time interval a3", "average revisit time interval a4" and "week target observation total duration a5" judging the relative importance of each other. Because there is the comparison of the five indexes between the two, to form a 5 x5 matrix, and the meanings of each element in the matrix are as shown in Table 3.

Table 3. Judgment matrix

a1/a1 Relative importance	a1/a2 Relative importance	a1/a3 Relative importance	a1/a4 Relative importance	a1/a5 Relative importance
a2/a1 Relative importance	a2/a2 Relative importance	a2/a3 Relative importance	a2/a4 Relative importance	a2/a5 Relative importance
a3/a1 Relative importance	a3/a2 Relative importance	a3/a3 Relative importance	a3/a4 Relative importance	a3/a5 Relative importance
a4/a1 Relative importance	a4/a2 Relative importance	a4/a3 Relative importance	a4/a4 Relative importance	a4/a5 Relative importance
a5/a1 Relative importance	a5/a2 Relative importance	a5/a3 Relative importance	a5/a4 Relative importance	a5/a5 Relative importance

The specific value of P_A is as follows:

$$\mathrm{P_A} = \begin{bmatrix} 0.5 & 0.8 & 0.7 & 0.8 & 0.7 \\ 0.2 & 0.5 & 0.4 & 0.6 & 0.4 \\ 0.3 & 0.6 & 0.5 & 0.7 & 0.6 \\ 0.2 & 0.4 & 0.3 & 0.5 & 0.3 \\ 0.3 & 0.6 & 0.4 & 0.7 & 0.5 \end{bmatrix} \tag{5}$$

P_B stand for the five belongs to the "regional target observation ability" three-level index, "the area covered by observation number b1", "all the area covering the time-consuming b2" and "objective observation total duration b3" judging the relative importance of each other. The meanings of each element in the matrix are as shown in Table 4.

Table 4. judgment matrix

b1/b1 Relative importance	b1/b2 Relative importance	b1/b3 Relative importance
b2/b1 Relative importance	b2/b2 Relative importance	b2/b3 Relative importance
b3/b1 Relative importance	b3/b2 Relative importance	b3/b3 Relative importance

The specific value of P_B is as follows:

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$$P_B = \begin{bmatrix} 0.5 & 0.7 & 0.7 \\ 0.3 & 0.5 & 0.5 \\ 0.3 & 0.5 & 0.5 \end{bmatrix} \tag{6}$$

P_C stand for the five belonging to level 3 indicators of a "moving target observation ability," access to the total number of c1 ", "maximum revisit time interval c2", "minimum revisit time interval c3", "average revisit time interval c4", "total duration c5 target observation" and "the whole observation ability c6" judging the relative importance of each other. The meanings of each element in the matrix are as shown in Table 5.

Table 5. Judgment matrix of $\boldsymbol{P_C}$

c1/c1 Relative importance	c1/c2 Relative importance	c1/c3 Relative importance	c1/c4 Relative importance	c1/c5 Relative importance	c1/c6 Relative importance
c2/c1 Relative importance	c2/c2 Relative importance	c2/c3 Relative importance	c2/c4 Relative importance	c2/c5 Relative importance	c2/c6 Relative importance
c3/c1 Relative importance	c3/c2 Relative importance	c3/c3 Relative importance	c3/c4 Relative importance	c3/c5 Relative importance	c3/c6 Relative importance
c4/c1 Relative importance	c4/c2 Relative importance	c4/c3 Relative importance	c4/c4 Relative importance	c4/c5 Relative importance	c4/c6 Relative importance
c5/c1 Relative importance	c5/c2 Relative importance	c5/c3 Relative importance	c5/c4 Relative importance	c5/c5 Relative importance	c5/c6 Relative importance
c6/c1 Relative importance	c6/c2 Relative importance	c6/c3 Relative importance	c6/c4 Relative importance	c6/c5 Relative importance	c6/c6 Relative importance

The specific value of P_C is as follows:

$$P_C = \begin{bmatrix} 0.5 & 0.7 & 0.8 & 0.8 & 0.7 & 0.9 \\ 0.3 & 0.5 & 0.7 & 0.7 & 0.6 & 0.8 \\ 0.2 & 0.3 & 0.5 & 0.6 & 0.4 & 0.7 \\ 0.2 & 0.3 & 0.4 & 0.5 & 0.4 & 0.6 \\ 0.3 & 0.4 & 0.6 & 0.6 & 0.5 & 0.7 \\ 0.1 & 0.2 & 0.3 & 0.4 & 0.3 & 0.5 \end{bmatrix} \tag{7}$$

The above matrix is summed by rows, and $r_{ij} = \frac{r_i - r_j}{2(n-1)} + 0.5$ is converted to form the following fuzzy consistency judgment matrix.

$$F_P^R = \begin{bmatrix} 0.5000 & 0.5500 & 0.6000 \\ 0.4500 & 0.5000 & 0.5500 \\ 0.4000 & 0.4500 & 0.5000 \end{bmatrix} \tag{8}$$

$$P_A^R = \begin{bmatrix} 0.5000 & 0.6400 & 0.5800 & 0.6800 & 0.6000 \\ 0.3600 & 0.5000 & 0.4400 & 0.5400 & 0.4600 \\ 0.4200 & 0.5600 & 0.5000 & 0.6000 & 0.5200 \\ 0.3200 & 0.4600 & 0.4000 & 0.5000 & 0.4200 \\ 0.4000 & 0.5400 & 0.4800 & 0.5800 & 0.5000 \end{bmatrix} \tag{9}$$

$$P_B^R = \begin{bmatrix} 0.5000 & 0.6000 & 0.6000 \\ 0.4000 & 0.5000 & 0.5000 \\ 0.4000 & 0.5000 & 0.5000 \end{bmatrix} \tag{10}$$

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$$P_C^R = \begin{bmatrix} 0.5 & 0.5667 & 0.6417 & 0.6667 & 0.6083 & 0.7167 \\ 0.4443 & 0.5000 & 0.5750 & 0.6000 & 0.5417 & 0.6500 \\ 0.3583 & 0.4250 & 0.5000 & 0.5250 & 0.4667 & 0.5750 \\ 0.3333 & 0.4000 & 0.4750 & 0.5000 & 0.4417 & 0.5500 \\ 0.3917 & 0.4583 & 0.5333 & 0.5583 & 0.5000 & 0.6083 \\ 0.2833 & 0.3500 & 0.4250 & 0.4500 & 0.3917 & 0.5000 \end{bmatrix} \tag{11}$$

Calculate the weight according to the above weight calculation steps, and the result is shown in Figure 1.

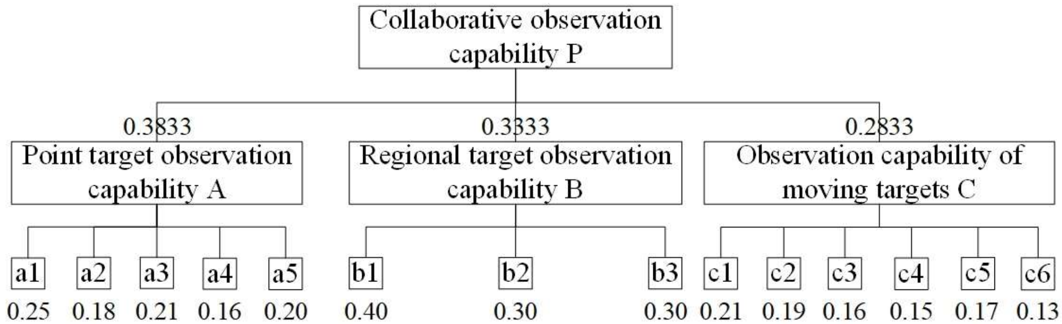

Figure 2. Weight allocation of evaluation indicators

Accordingly, the evaluation formula of satellite cooperative observation capability is as follows:

Point target observation capability:

$$A = a1 \times 0.25 + a2 \times 0.18 + a3 \times 0.21 + a4 \times 0.16 + a5 \times 0.2 \tag{12}$$

Regional target observation capability:

$$B = b1 \times 0.4 + b2 \times 0.3 + b3 \times 0.3 \tag{13}$$

Observation capability of moving target:

$$\mathrm{C} = \mathrm{c1} \times 0.2133 + \mathrm{c2} \times 0.1867 + \mathrm{c3} \times 0.1567 + \mathrm{c4} \times 0.1467 + \mathrm{c5} \times 0.17 + \mathrm{c6} \times 0.1267 \tag{14}$$

Satellite cooperative observation capability:

$$P = A \times 0.3833 + B \times 0.3333 + C \times 0.2833 \tag{15}$$

2.3. determine the scoring method of performance indicators

Based on the above index system, the overall observation capability of satellite resources and the overall observation capability of satellite coordination are quantitatively analyzed and calculated. In order to carry out quantitative evaluation, the scoring method is determined for each value of leaf nodes performance indicators. The dimensionality normalization of various performance indicators is realized through the scoring mechanism to solve the problem of dimensional inconsistency.

The scoring method of the evaluation indexes located at the leaf nodes in the above indicator system is given, as shown in Table 6.

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Table 6. Quantitative scoring methods for each indicator

Indicators	Sub-index	Evaluation score
Point target observation capability	Total number of weekly target visits	A score of 0.1 per visit.
	Maximum revisit interval	The maximum revisit interval is 0.0001 minute for every 1 second.
	Minimum revisit interval	Minimum revisit time interval of every 1 second, loss of 0.0001 points.
	Mean revisit interval	Average revisit time interval of every 1 second, loss of 0.0001 points.
	Total duration of weekly target observation	The total time of observation is 0.1 minutes per second.
Regional target observation capability	Total coverage of the region	For each observation, 0.01 points were lost.
	Full coverage of the area takes time	Full coverage takes every 1 second, loss of 0.00001 minutes.
	Total time of target observation	Observation total duration for every 1 second, loss of 0.01 points.
Moving target observation capability	Total number of target visits	Each visit will earn 0.1 points, up to 10 points.
	Maximum revisit interval	The maximum revisit interval is 0.0001 minute for every 1 second, and up to 10 minutes are lost.
	Minimum revisit interval	The minimum revisit interval is 0.0001 minute for every 1 second, and up to 10 minutes are lost.
	Mean revisit interval	The average revisit interval is 0.0001 minute for every 1 second, and up to 10 minutes are lost.
	Total time of target observation	The total duration of observation is 0.1 minutes per second, up to 10 minutes.
	Whole-course observation capability	10 points for having the ability to observe the whole course; If you do not have it, you get 0.

3. Result analysis

Aiming at three typical observation tasks of point target observation, regional target observation and moving target accompanying, three kinds of observation task determination are designed, which compare and analyze the observation effects of using resource satellites alone and using resources satellites and GF[13] series satellites to observe earth observation resources in terms of the total number of target visits per unit time, the maximum revisiting time interval, the total cumulative target observation time per unit time, the time-consuming of regional full coverage and the continuous accompanying ability of targets. Finally, based on the analysis results, the improvement of remote sensing observation capability brought by GF series and other satellites is evaluated.

3.1. Scenario 1: analysis of the improvement of target observation capability

Taking satellite observation of point targets as an example, we compare and analyze the differences in the total number of weekly visits, the maximum revisiting time interval, the minimum revisiting time interval, the average revisiting time interval and the total observation time of the weekly target under the two conditions, and illustrate the

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improvement of remote sensing observation ability of point targets by satellite cooperation, as shown in Table 7.

Table 7. Improvement of target observation capability

Observation resources		a1	a2	a3	a4	a5
Resource satellite	Test	112	7h 51min 14s (28274s)	0	1h 34min 23s (5663s)	1min 59s (119s)
	Score	11.2	-2.8274	0	-0.5663	11.9
Satellite synergy	Test	167	6h 29min 3s (23343s)	0	58min35s (4515s)	2min 36s (156s)
	Score	16.7	-2.3343	0	-0.3515	15.6

According to the point target observation ability, the quantitative evaluation formula is as follows:

Target observation capability of resource satellite points:

$$= a1 \times 0.25 + a2 \times 0.18 + a3 \times 0.21 + a4 \times 0.16 + a5 \times 0.2$$

$$= 11.2 \times 0.25 + 2.8276 \times 0.18 + 0 \times 0.21 + 0.5663 \times 0.16 + 11.9 \times 0.2$$

$$= 4.5805$$

Satellite cooperative application point target observation capability:

$$= \mathrm{a1} \times 0.25 + \mathrm{a2} \times 0.18 + \mathrm{a3} \times 0.21 + \mathrm{a4} \times 0.16 + \mathrm{a5} \times 0.2$$

$$= 16.7 \times 0.25 - 2.3343 \times 0.18 + 0 \times 0.21 - 0.3515 \times 0.16 + 15.6 \times 0.2$$

$$= 6.8186$$

The improvement of point target observation capability is as follows:

$$\frac{6.8186 - 4.5805}{4.5802} * 100\% = 48.8712\%$$

3.2. Scenario 2: analysis of the improvement of regional target observation capability

Regional satellite observations of a sea area is carried out, for example, by comparing the analysis using the resource satellite observations alone and at the same time use of resources and GF series satellites for collaborative observation, under the condition of two kinds of regional whole observation times, for the whole time consuming and target situation of observed total duration from three aspects, that ability of the satellite remote sensing observation on regional targets together, as shown in Table 8. Target observation is shown in Figure 5 and Figure 6.

Table 8. Improvement of regional target observation capability

Observation resources		b1	b2	b3
Resource satellite	Test	20	18h 56min 39s (68199s)	34min 37s (2077s)
	Score	-2	-6.8199	-207.7
Satellite synergy	Test	14	7h 51min 56s (28316s)	25min 02s (1502s)
	Score	-1.4	-2.8316	-150.2

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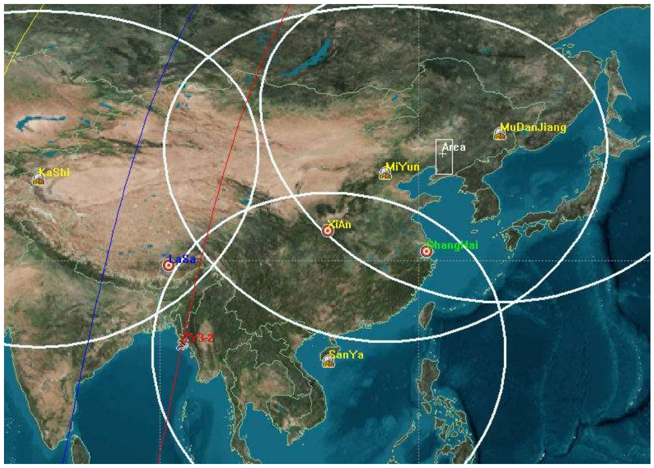

Figure 5. Schematic diagram of resource satellite's access to regional targets

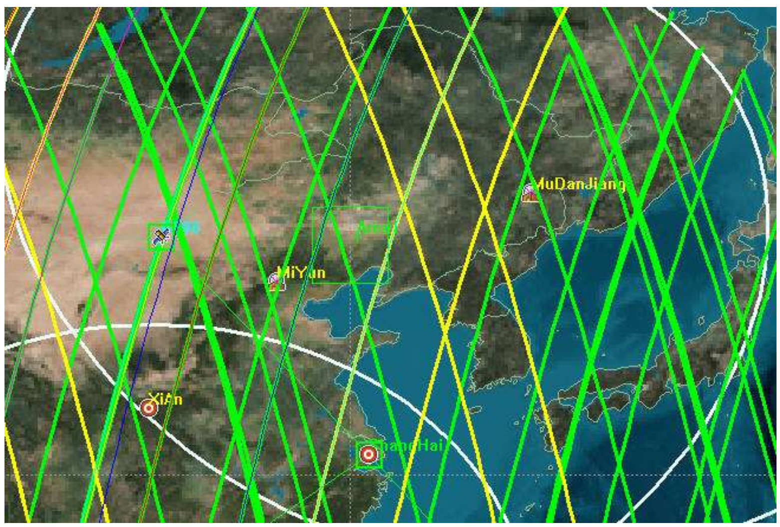

Figure 6. Schematic diagram of GF-Resource satellite joint access to regional targets

According to the point target observation ability, the quantitative evaluation formula is as follows:

To make sure the value is positive, set the initial score to 10 in both cases.

Regional target observation capability of resource satellite

$$= 10 + \mathrm{b1} \times 0.4 + \mathrm{b2} \times 0.3 + \mathrm{b3} \times 0.3$$

$$= 10 - 0.2 \times 0.4 - 0.68199 \times 0.3 - 20.77 \times 0.3$$

$$= 3.4844$$

Satellite coordinated regional target observation capability

$$= 10 + \mathrm{b1} \times 0.4 + \mathrm{b2} \times 0.3 + \mathrm{b3} \times 0.3$$

$$= 10 - 0.14 \times 0.4 - 0.28316 \times 0.3 - 15.02 \times 0.3$$

$$= 5.35305$$

The improvement of regional target observation capability is as follows:

$$\frac{5.35305 - 3.4844}{3.4844} * 100\% = 53.6290\%$$

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Using resource satellites to observe the belt coverage of a certain area, it takes a total of 20 visits to cover the entire waters, which takes 18 hours 56 minutes and 39 seconds. While using resource satellites and GF series satellites to perform collaborative observation of the sea area with strip coverage, only 14 times can achieve full coverage. It takes 7 hours, 51 minutes and 56 seconds, which is 11 hours, 4 minutes and 43 seconds less than using the resource satellite observations alone.

3.3. Scenario 3: analysis on the improvement of dynamic target observation ability

Each satellite has its own usage characteristics, through the analysis of the characteristics of the use of satellites, it is found that the combination of some satellites with special usage modes and resource satellites can achieve an innovative way of earth observation and achieve unprecedented observation effect.

Take GF-4 satellite as an example, which is a geostationary orbit satellite with a fixed position of 105.6°E. The observation range covers the area of 7000 km × 7000 km in China's territory and surrounding areas. The single-scene imaging area covers 400 km × 400 km or more. It can be realized by satellite attitude maneuver for any position within the scope of observations, and can realize fast point to the target area. The GF-4 satellite has the ability to repeat observation for 20 seconds and has working modes such as staring mode, mobile patrol mode, regional mode and general survey mode. The payload contains a visible 50 meters/medium wave infrared resolution of 400 meters, more than 400 km width stare at the camera.

According to the characteristics of the GF-4 satellite mentioned above, if it can be used in conjunction with other satellites, continuous concomitant observation of large oil tankers on the surface can be formed. The specific observation steps are as follows:

(1) locate the large oil tankers, when other relevant satellites find them;

(2) according to the position of the large oil tanker determined by the observation satellite, the GF-4 satellite shall be guided to conduct image observation of the region;

(3) when the position of the large oil tanker changes, the satellite direction can be adjusted rapidly according to the new position of the large oil tanker, so as to realize the continuous companion of the large oil tanker. In addition, based on the real-time location of the large tanker, other medium and low orbit imaging satellites with access opportunities are called to observe the large tanker.

Taking the movement track of the large oil tanker passing through the western Pacific Ocean to the East China Sea as an example, this paper compares and analyzes the observation by using resources satellite alone and the observation by using resources satellite and GF series satellites at the same time. The differences in the total number of target visits, the maximum revisiting time interval, the minimum revisiting time interval, the average revisiting time interval, the total observation time of the target and the whole observation ability under the two conditions illustrate the improvement of the remote sensing observation ability of satellites such as high score series to moving targets, as shown in Table 9. Target observation is shown in Figure 7 and Figure 8.

Table 9. Improvement of observation ability of moving targets

Observation resources		c1	c2	c3	c4	c5	c6
Resource satellite	Test	155	5h 16min 46s (19006s)	0	1h 1min 51s (3711s)	2min 29s (149s)	Discontinuous
	Score	15.5	-1.9006	0	-0.3711	-0.0149	0
GF-4	Test	Continuous	0	0	0	Continuous	Continuous
	Score	10	0	0	0	10	10

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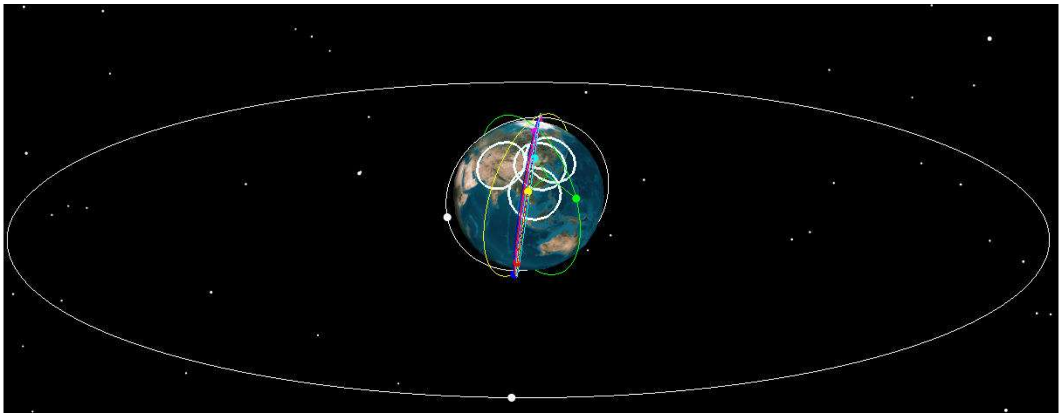

Figure 7. 3D diagram of the GF - resource satellite joint access to a moving target

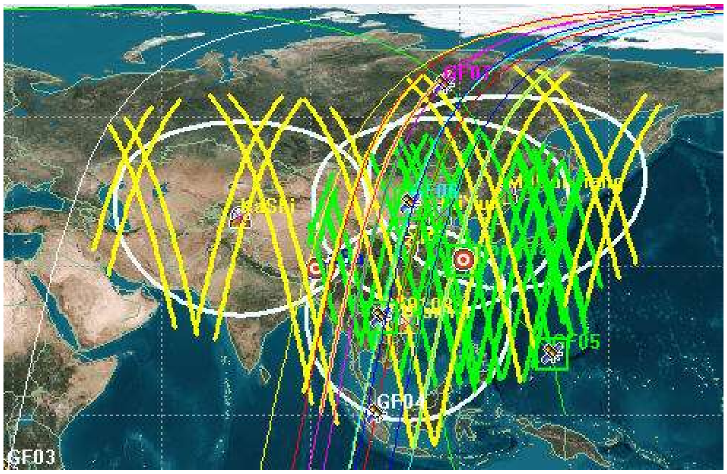

Figure 8. 2D diagram of the GF-resource satellite joint access to a moving target

Resource satellite dynamic target observation capability

$$= c1 \times 0.2133 + c2 \times 0.1867 + c3 \times 0.1567 + c4 \times 0.1467 + c5 \times 0.17 + c6 \times 0.1267$$

$$= 15.5 \times 0.2133 - 1.9006 \times 0.1867 + 0 \times 0.1567 - 0.3711 \times 0.1467 - 0.0149 \times 0.17 + 0 \times 0.1267$$

$$= 2.8943$$

Satellite coordinated moving target observation capability

$$= c1 \times 0.2133 + c2 \times 0.1867 + c3 \times 0.1567 + c4 \times 0.1467 + c5 \times 0.17 + c6 \times 0.1267$$

$$= 10 \times 0.2133 + 0 \times 0.1867 + 0 \times 0.1567 + 0 \times 0.1467 + 10 \times 0.17 + 10 \times 0.1267$$

$$= 5.1$$

The improvement of dynamic target observation ability is as follows:

$$\left|\frac{5.1 - 2.8943}{2.8943}\right| * 100\% = 76.2084\%$$

The comparison of remote sensing observation capability between resource satellite and satellite coordination is as follows:

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Resource satellite observation capability

$$= 4.5802 \times 0.3833 + 3.4844 \times 0.3333 + 2.8943 \times 0.2833$$

$$= 3.7369$$

Satellite cooperative observation capability

$$= 6.8186 \times 0.3833 + 5.35305 \times 0.3333 + 5.1 \times 0.2833$$

$$= 5.8426$$

The overall capability of remote sensing observation has been improved

$$= \frac{5.8426 - 3.7369}{3.7369} * 100\% = 56.3488\%$$

Using resource satellites to observe the driving process of large oil tankers, there are 155 observation opportunities during the entire movement of the large oil tanker. The length of each observation is only 1~2 seconds, and the cumulative observation time is only 2 minutes 29 seconds. The maximum revisit time interval is as long as 5 hours, 16 minutes and 46 seconds, and the average revisit time interval is as long as 1 hour, 01 minutes and 51 seconds. Therefore, from the point of observation effects, only the moving target can be observed intermittently, and the continuous observation effect cannot be formed.

GF-4 satellite is used to conduct accompanying observation on moving targets. The observation range of GF-4 satellite is a region of 7,000 km× 7,000 km in China's territory and surrounding areas, and its single-scene staring range is 400km×400km. The visible light near-infrared resolution of GF-4 satellite payload is 50m, and the mid-wave infrared resolution is 400m. With the help of other means, satellites can find the rough orientation of large oil tankers, and guide GF-4 satellite to carry out optical image observation on large oil tankers. Due to the large oil tanker is the maximum speed of 30 knots, 56 km/hour, and the gaze range of single-scene is 400km, it is difficult for large oil tanker to jump out of the continuous observation range of GF-4 satellite, so it can form a complete observation. The capability improvement effect brought by GF-4 satellite for moving target observation is very obvious. Observation opportunities are spread throughout the entire movement of the target, and continuous observation can be made for the whole movement of the target. The maximum revisit interval is reduced to 0, and the average revisit interval is reduced to 0.

4. Conclusions

Based on the new satellite capability and characteristics in recent years, this paper designs the satellite cooperative application capability evaluation model, scenario and method. We introduce the structure of the evaluation model and the functional composition of the system, the relationship between the evaluation process and the evaluation index factors. Through the real orbit data, this paper evaluates the effect of satellite cooperative application on the improvement of remote sensing observation capability. The evaluation results show that the satellite cooperative application can significantly improve the overall remote sensing observation capability.

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References

1. Feng Ni, Jinchun Gao, Gang Xie, Yuanan Liu, Bibo Hu and Jingchao Wang, "Network traffic load balancing method with GEO satellites cooperation," *10th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM 2014)*, Beijing, 2014, pp. 393-397.
2. X. Guo, H. Zhou and G. Liu, "Service oriented cooperation architecture for distributed satellite networks," *2015 International Conference on Wireless Communications & Signal Processing (WCSP)*, Nanjing, 2015, pp. 1-5.
3. T. Yanagimachi and Y. Ishida, "Effect of formation control for multiple satellite cooperation system," *2016 International Conference On Advanced Informatics: Concepts, Theory And Application (ICAICTA)*, George Town, 2016, pp. 1-4.
4. L. Hui *et al*., "A cooperation earth observation model of SAR satellite and optical remote sensing satellite," *2014 IEEE Geoscience and Remote Sensing Symposium*, Quebec City, QC, 2014, pp. 584-587.
5. Z. Wen-bo, S. Peigen, L. Zhi-guo and X. Haifeng, "An intrusion detection model for satellite network," *2010 2nd IEEE International Conference on Information Management and Engineering*, Chengdu, 2010, pp. 167-170.
6. W. Shi-Xing, W. Jin-Hua and T. Liang, "Task allocation for multi-satellite cooperation based on estimation of distribution algorithm," *Proceedings of the 31st Chinese Control Conference*, Hefei, 2012, pp. 2548-2553.
7. D. Zhang and N. Yu, "Self-Assembly Method for Cooperation of Multi-satellites," *2015 8th International Symposium on Computational Intelligence and Design (ISCID)*, Hangzhou, 2015, pp. 408-412.
8. J. C. A. van der Lubbe and E. Backer, "Hierarchical classification inference for fuzzy data analysis," *Proceedings of 3rd International Symposium on Uncertainty Modeling and Analysis and Annual Conference of the North American Fuzzy Information Processing Society*, College Park, MD, USA, 1995, pp. 402-407.
9. K. Laib, A. Korniienko, M. Dinh, G. Scorletti and F. Morel, "Hierarchical Robust Performance Analysis of Uncertain Large Scale Systems," in *IEEE Transactions on Automatic Control*, 63(07), pp. 2075-2090, July 2018.
10. Voisin, V. A. Krylov, G. Moser, S. B. Serpico and J. Zerubia, "Supervised Classification of Multisensor and Multiresolution Remote Sensing Images With a Hierarchical Copula-Based Approach," in *IEEE Transactions on Geoscience and Remote Sensing*, 52(06), pp. 3346-3358, 2014.
11. Y. Zhang, Y. Yuan, Y. Feng and X. Lu, "Hierarchical and Robust Convolutional Neural Network for Very High-Resolution Remote Sensing Object Detection," in *IEEE Transactions on Geoscience and Remote Sensing*, 57(08), pp. 5535-5548, Aug. 2019.
12. L. Rongjie, Z. Jie, S. Pingjian, S. Fengjing and L. Guanfeng, "An Agglomerative Hierarchical Clustering Based High-Resolution Remote Sensing Image Segmentation Algorithm," *2008 International Conference on Computer Science and Software Engineering*, Hubei, 2008, pp. 403-406.
13. Song Ting, Gong Shao-qi, Liu Jun-zhi, Gu Zheng-fan, Shi Jun-zhe, Wu Wei. Performance Assessment of Atmospheric correction for Multispectral Data of GF-4 on Inland Case Ⅱ Turbid Water [J] *Spectroscopy and Spectral Analysis*, 38(04), 2018: 1191-1197.