Analysis of Systematic Contribution Rate of TDRSS in the Remote Sensing Satellite System

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Abstract. The application of TDRSS in the low orbit remote sensing satellites system can improve the effectiveness of remote sensing satellites. This paper built an evaluation system of remote sensing satellites from observation ability, response ability, data transmission ability and control ability. And linear weighting method was used for quantitative analysis of systematic contribution rate of TDRSS. As shown by the analysis result, TDRSS can improve the response ability, data transmission ability and control ability.

1. Introduction

The remote sensing satellites can cover the different regions of earth and transfer the observation data back to earth, which can be used to analyze, monitor. According to different service loads, such as visible light camera, infrared camera, multispectral scanner, SAR, remote sensing satellites can be divided into meteorological satellites, land resource satellites, ocean satellites[1]. The remote sensing satellites have many contributions to the economy development of our country. How to utilize the limited satellites resource to accomplish more remote sensing tasks is an important issue to discuss.

If we want to improve the application effectiveness of remote sensing satellites, we must react quickly based on the status monitor and provide continuous data transmission support to the remote sensing satellites. The measurement stations and data receive stations located on ground can only communicate with satellites in sight distance. Limited by the area and economic condition, we can not locate the ground stations all over the world. As a result, we can not accomplish the real-time transmission of massive remote sensing data from satellites based on the ground stations. Tracking and Data Relay Satellite System (TDRSS) can solve the problems of low coverage rate of measurement and data transmission. Supported by TDRSS, the application effectiveness of remote sensing satellites can be improved remarkably. This paper focused on the ability evaluation system of remote sensing satellites and used linear weighting method to analyze the application effectiveness of TDRSS. The key indexes of remote sensing satellites were compared between supported by TDRSS and ground stations.

2. Application mode of remote sensing satellites supported by TDRSS

2.1. Introduction of TDRSS

TDRSS is designed as a highly automated user driven and controlled system for supporting customer spacecraft tracking and data acquisition. TDRSS is a tracking and data communication network conceived and designed to provide improved orbital coverage of low earth orbiting LEO missions, as
well as increase the data capacity throughput of those missions. A full constellation of satellites would allow coverage of the majority of a LEO mission’s orbit versus the approximately 15% coverage provided by a network of ground stations located around the world. Each TDRS can simultaneously provide up forward services and return services. The forward services refer to the link from the customer terrestrial location to the ground station, to TDRS, to the user platform. The return services refer to the link from the user platform, to TDRS, to the ground station, to the customer terrestrial location. The customers supported by TDRSS include: Hubble Space Telescope, TERRA, LSAT, SWIFT, ERBS, AQUA, AURAF and so on. Table 1 provides the performance indexes of the second generation TDRS. The space-to-space link between the user and TDRS can be at S-band, Ku-band or Ka-band. The data transmission rate can be up to 2*300Mbps[2].

Table 1. Performance indexes of the second generation TDRS.

| 2nd Generation of TDRS | manufacturer | Boeing Company |
|------------------------|--------------|----------------|
| phased array antenna   | 47 array elements (15 forward elements, 32 return elements) |
| single address antenna | Diameter: 4.6m, Pointing range: ±22° (west to east), ±28° (south to north) |
| **forward link**        |              |                |
| s band multi-access    | number of user per TDRS: 1, max data rate: 300kbit/s |
| s band single-access   | number of user per TDRS: 2, max data rate: 7Mbit/s |
| Ku band single access  | number of user per TDRS: 2, max data rate: 25Mbit/s |
| Ka band single access  | number of user per TDRS: 2, max data rate: 7Mbit/s |
| **return link**        |              |                |
| s band multi-access    | number of user per TDRS: 5, max data rate: 3Mbit/s |
| s band single-access   | number of user per TDRS: 2, max data rate: 6Mbit/s |
| Ku band single access  | number of user per TDRS: 2, max data rate: 300Mbit/s |
| Ka band single access  | number of user per TDRS: 2, max data rate: 300Mbit/s |
| tracking distance measurement accuracy | 150m (3σ) |

2.2. Application mode of TDRSS supporting remote sensing satellite

2.2.1. System structure. As shown in Fig.1, the application system of remote sensing satellite supported by TDRSS is constructed by space segment and ground segment. The space segment includes TDRS, remote satellites with user terminals. The ground segment includes remote sensing satellite application center, remote sensing satellite control center, TDRSS ground station and TDRSS control center. The remote sensing satellite control center is responsible for task planning, control instruction producing and telemeasuring data analyzing. The remote sensing satellite control center can make sure that the remote sensing satellite can implement observing tasks and data transmission tasks as the planned tasks. The remote sensing satellite application center is responsible for the remote sensing data processing and distribution to the data user departments. The ground station and control
center of TDRSS are responsible for the control of TDRS, and transmitting the forward data and return data of remote sensing satellite.

2.2.2. System operational process. The operational process of remote sensing satellite system supported by TDRSS mainly includes observing tasks planning, data relay and transmission tasks planning, observe and control instruction producing and uploading, remote sensing observations, data transmission and processing.

- **Observing tasks planning.** Depending on the remote observing tasks, the remote sensing satellite control center produces the observing plans, data transmission plans, telemetry and commanding plans by considering different observing technical methods, available data transmission resources and telemetry and command resources.

- **Data relay and transmission tasks planning.** Depending on the data transmission plans, telemetry and commanding plans, the control center of TDRSS produces the related data tracking and relay plans.

- **Observe and control instruction producing and uploading.** The control center of remote sensing satellites produces control instructions according to the control characteristic. The control instructions will be sent to the control center of TDRSS in time according to the data relay and transmission plans. And the control center of TDRSS will transmit the instructions to the remote sensing satellite through TDRS.

- **Remote sensing observations.** The remote sensing satellite executes control instructions to observe predetermined targets and environment.

- **Data transmission and processing.** According to the data tracking and relay plans, TDRSS will establish the parameters of TDRS and related receiving equipment in order to track the remote sensing satellite, transmit the observation data and distribute to the application center of remote sensing satellites. The data transmission can be simultaneous with observation or afterwards as needed.
3. Efficiency Evaluation

3.1. Evaluation index system of remote sensing satellites application

Application efficiency evaluation is based on the construction of scientific index system. As one kind of information acquisition methods, the basic framework and layered index system of the remote sensing satellites are constructed based on the information categoricalness, accuracy and timeliness in reference [4]. The mission oriented evaluation index system of the remote sensing satellites is constructed based on system theory in reference[5], in which the effective duration is the core index.

In this paper, according to the principles such as levels, measurability, systematicness, independence and sensitivity, the abilities of the remote sensing satellites are summarized to four aspects, which are observational capability, quick response ability, data transmission ability and control ability. Observational capability means the observation target recognition ability of the remote sensing satellites. Observational capability includes observation range, imaging spectral, imaging quality, spatial resolution and so on. Quick response ability means the response time of the remote sensing satellites system to execute the observation tasks, in which the time of task planning, instructions producing, instructions transmission (time delay included), imaging and data distribution are included. Data transmission ability means the ability of the transmission of observation data from the remote sensing satellites to the application center, in which the data size of transmission and success ratio of transmission are included. Control ability means the management ability of the control center to the remote sensing satellites and ground systems, in which the orbit coverage rate of the remote sensing satellites, the success ratio of instructions producing, instructions transmission and instructions execution are included.

Table 2. Evaluation index system of Remote sensing satellites application.

| Ability index Criterion index |
|-----------------------------|
| Observation ability          |
| observation range            |
| imaging spectral            |
| imaging quality             |
| spatial resolution          |
| Quick response ability       |
| Time of task planning        |
| time of instructions producing|
| Time of instructions transmission (time delay included) |
| Time of imaging             |
| Time of data distribution    |
| Data transmission ability    |
| data size of transmission    |
| success ratio of transmission|
| Control ability              |
| orbit coverage rate          |
| success ratio of instructions producing |
| success ratio of instructions transmission |
| success ratio of instructions execution |

3.2. Evaluation method

According to the evaluation index system, the application efficiency of remote sensing satellites supported by TDRSS and supported by ground stations are evaluated and compared in this paper. We
must explain that among the evaluation indexes, the observation ability indexes are only related to the observation loads on remote sensing satellites, which are unrelated to the supporting by TDRSS. So the quick response ability, data transmission ability and control ability are mainly discussed in this paper. As an example, the quick response ability evaluation method is illustrated below.

The quick response ability includes time of task planning, instructions producing, instructions transmission, imaging, data distribution. Referring to the system indexes of remote sensing satellites, we can get the values of performance indexes. And the quick response ability is evaluated based on the values.

Firstly, the normative approach is operated to the original values of different indexes, $X_{ni}$, to get the evaluation values.

$$C_{ni} = \frac{X_{ni}}{\sqrt{\sum_i X_{ni}^2}}$$

in which $n$ means the different second class ability indexes, $i$ means the different third class ability indexes. Then the linear weighting method is used to evaluate the second class indexes $B_n$, in which $W_{ni}$ is the third class indexes weighting.

$$B_n = \sum_i W_{ni} C_{ni}$$

3.2.1. Quick response ability evaluation

The quick response ability is evaluated by five indexes, which are time of task planning, time of instructions producing, time delay of instructions transmission, time of imaging, time delay of data distribution. Time of task planning means the control center of remote sensing satellites takes time to allocate the satellites observation resource and produce the resource allocation formula according to the observation mission requirement and task assignment strategies. This index is determined by the ability of task planning system of control center. Usually the planning time of single task is less than 5 minutes. Time of instructions producing means the control center of remote sensing satellites takes time to produce the control instructions of satellite platform and observation loads. This index is determined by the satellites tracking, telemetry, and command ability of control center. Usually the time of instructions producing of one satellite is less than 5 minutes. Time delay of instructions transmission means the time from the instructions produced to transmission completed. If the control of satellite is only supported by the ground stations, we can not assure that the satellite is always visible to the ground stations. So after the the instructions are produced, the time delay of instructions transmission is about 90 minutes. If the control of satellite is supported by TDRSS, three TDRS can assure the 100 percent orbit coverage of low orbit satellites, which means the instructions produced can be transmitted to remote sensing satellites in real time, the time delay is less than 1 minute. Time of imaging means the observation load takes the time to complete the observation and imaging. The index is usually less than 5 minutes, which is determined by the working model of observation load, target area and imaging region. The time delay of data distribution means the time from imaging completed to the data transmission to application center completed. Without the supporting of TDRSS, we can not assure that the satellite is always visible to ground stations. As a result, the observation data is usually stored on the remote sensing satellite, and data transmission is completed when the remote satellite is visible to the ground stations. The time delay of ground station transmission is usually 4 hours. But supported by TDRSS, the data transmission can be real time and the time delay is usually less than 1 minute.

| Time of task planning | Time of instructions | Time delay of instructions | Time of imaging | Time delay of data |
|-----------------------|----------------------|---------------------------|----------------|-------------------|

Table 3. Index values of quick response ability.
X11 producing X12 transmission X13 distribution X14

Supported by ground stations (A1)
5min 10s 90min 5min 240min

Supported by TDRSS (A2)
5min 10s 1min 5min 1min

Normative approach is executed to the index values of quick response ability, and the result is given in Table 4.

Table 4. Normative approach values of quick response ability.

| Time of task planning normalized value (C11) | Time of instructions producing normalized value (C12) | Time delay of instructions transmission normalized value (C13) | Time of imaging normalized value (C14) | Time delay of data distribution normalized value (C15) |
|--------------------------------------------|---------------------------------------------------|----------------------------------------------------------|----------------------------------|----------------------------------|
| Supported by ground stations (A1)          | 0.71                                              | 0.99                                                     | 0.71                             | 0.99                             |
| Supported by TDRSS (A2)                    | 0.71                                              | 0.01                                                     | 0.71                             | 0.004                            |

Considering the different characteristics of indexes, we assumed the weighing vector of indexes is \( w = (0.2, 0.2, 0.2, 0.2, 0.2) \). Then the evaluation result of quick response ability can be calculated as the weighing method as below.

\[
A1 = 0.822 ; A2 = 0.429
\]

3.2.2. Data transmission ability evaluation
The evaluation of data transmission ability is focus on the data size of transmission and success ratio of transmission. The data size of transmission means the observation data size transmitted by the remote sensing satellite through ground stations or TDRSS in one round circle. Usually the maximum data transmission rate through ground stations is 1.5Gbps, while the maximum data transmission rate through TDRSS is 2*300Mbps. The data transmission time in one round circle of remote sensing satellite is determined by the orbit coverage rate and available time of transmission load. Limited by the visible region, the data transmission time through ground station is less than 5 minutes, while the data transmission time through TDRSS is less than 30 minutes. Then the data size of transmission is about 450Gbps through ground station, and is about 1080Gbps through TDRSS. The success ratio of transmission is usually above 99%.

Table 5. Index values of data transmission ability.

| Data size of transmission X21 | Success ration of data transmission X22 |
|-------------------------------|----------------------------------------|
| Supported by ground stations (A1) | 450Gb | 0.99 |
| Supported by TDRSS (A2)           | 1080Gb | 0.99 |
Normative approach is executed to the index values of data transmission ability, and the result is given below.

Table 6. Normative approach values of data transmission ability

|                  | Data size of transmission X21 | Success ration of data transmission X22 |
|------------------|-------------------------------|----------------------------------------|
|                  | normalized value(C21)         | normalized value(C22)                  |
| Supported by ground stations (A1) | 0.38                         | 0.71                                   |
| Supported by TDRSS (A2)          | 0.92                         | 0.71                                   |

Assumed the weighing vector of indexes is \( w=(0.6, 0.4) \). Then the evaluation result of data transmission ability can be calculated as the weighing method as below.

\[
A1=0.51; A2=0.84
\]

3.2.3. Control ability evaluation

The evaluation of control ability is focus on the the orbit coverage rate of the remote sensing satellites, the success ratio of instructions producing, instructions transmission and instructions execution. As an example, the orbit coverage of a single ground station to a typical low-orbit remote sensing satellite (recursion period is 90 minutes) is about 2%, while the orbit coverage of a single TDRS is about 54%. The success ratio of instructions producing is determined by the ability of control center, is usually 100%. The success ratio of instructions transmission is determined by the stability of transmission link from ground station or TDRSS to remote sensing satellite, which is usually more than 98%. The success ratio of instructions execution is determined by the ability of measurement and control system of remote sensing satellite, which is usually 100%.

Table 7. Index values of control ability.

|                  | orbit coverage rate X31 | success ratio of instructions producing X32 | success ratio of instructions transmission X33 | success ratio of instructions execution X34 |
|------------------|-------------------------|-------------------------------------------|-----------------------------------------------|---------------------------------------------|
| Supported by ground stations (A1) | 0.02              | 1                                          | 0.98                                         | 1                                           |
| Supported by TDRSS (A2)          | 0.54              | 1                                          | 0.98                                         | 1                                           |

Normative approach is executed to the index values of control ability, and the result is given below.

Table 8. Normative approach values of control ability.

|                  | X31 | X32 | X33 | X34 |
|------------------|-----|-----|-----|-----|
|                  | normalized | normalized | normalized | normalized |
value(C31) value(C32) value(C33) value(C34)

| Supported by ground stations (A1) | 0.037 | 0.71 | 0.71 | 0.71 |
|----------------------------------|-------|------|------|------|
| Supported by TDRSS (A2)          | 0.99  | 0.71 | 0.71 | 0.71 |

Assumed the weighing vector of indexes is \( w = (0.4, 0.2, 0.2, 0.2) \). Then the evaluation result of control ability can be calculated as the weighing method as below.

\( A1 = 0.439; A2 = 0.824 \)

3.3. Evaluation result

According to the quantitative processing of quick response ability, data transmission ability and control ability, the systematic ability evaluation result can be achieved as table 9. We need to explain that the quick response ability is evaluated by the indexes of response time, so the decrease of evaluation value means the improvement of quick response ability.

| Supported by ground stations | Supported by TDRSS |
|-----------------------------|--------------------|
| Quick response ability      | 0.822              | 0.429              |
| Data transmission ability   | 0.51               | 0.84               |
| Control ability             | 0.439              | 0.824              |

4. Conclusion

The application mode and working process of TDRSS in the remote sensing satellites are analyzed in this paper. By evaluating and comparing the abilities of quick response, data transmission and control of remote sensing satellites supported by TDRSS and ground stations, we can draw the conclusion that TDRSS can significantly improve the systematic application effectiveness of remote sensing satellites, especially the quick response ability and control ability.

References

[1] XU Qinghe, FAN Lijia, GAO Hongtao. Integrated Configuration Design of Platform and Payload for Remote Sensing Satellite[J]. Spacecraft Recovery and Remote Sensing, 2014(8):9-16.
[2] SHI Xibin, LI Benjin, WANG Kun. Development of Three Generations of Tracking and Data Relay Satellite System. Journal of Spacecraft TT&C Technology, 2011(30):1-8.
[3] LIU Feng, LI Lin, MENG Xin. Research on Construction Model of the Capacity Index System for Remote Sensing Satellite System[J]. Spacecraft Recovery and Remote Sensing, 2017(12):40-45.
[4] CHEN Taoyi, PENG Huixiang, WANG Bin. Efficiency Evaluation Index System Establishment for Disaster Emergency Monitoring Based on Remote Sensing Satellites[J]. Computer Measurement and Control, 2020, 28(9):256-261.
[5] PENG Geng. Index System Construction of Information Support Capability Evaluation of Remote Sensing Satellite Task-oriented[J]. Command Control & Simulation, 2019(4):15-19.
[6] LOU Baojuan, WANG Qulan, BAO Lixia. Construction of Intelligent Transportation System Evaluation System Based on Linearity-weighted-sum Method[J]. Traffic and Transportation, 2020(36):70-73.