Study on Autonomous Mission Management Method for Remote Sensing Satellites

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Abstract. A remote sensing satellite is an earth observation satellite that acquires ground image information in space. It plays an important role in various areas such as resource surveying, environment monitoring and geological mapping. As the number of satellites increases, observation missions become more diverse and complicated as well as growing rapidly. Current implementations of remote sensing satellite observation missions still greatly depend on the ground operation control system. Multi-satellite and multi-function mission management, planning and uplink control also complicate the use of satellites by users. A key problem is how to improve the intelligence level and observation efficiency of on-orbit remote sensing satellites, while developing the overall efficiency of the satellite system for the convenience of users and also reducing the on-orbit operational cost. This article proposes an autonomous mission management strategy, which is based on the traditional mission management mode used by low-orbit remote sensing satellites. An implementation method for on-orbit mission rationality judgment, decoupling and instruction sequence generation is also established. This strategy aims to improve the intelligence level of remote sensing satellites and provide reference and guidance for future mission implementation of mission-oriented remote sensing satellites.

Keywords: Remote sensing satellite · Mission management · Autonomous

1 Introduction

A remote sensing satellite is an earth observation satellite that acquires ground image information from a spaceborne payload. It is currently the most widely-used and most typical satellite type and comprises the largest number of satellites launched worldwide [1]. The function and on-orbit working mode of early models were relatively simple. The design was based on a command-oriented mode, which meant that the ground operation control system had to implement mission planning, plan generation, mission instruction set scheduling and code injection for each observation before the satellite could initialize execution of various operating modes using the loaded instruction set. In these models, the implementation of satellite observation missions greatly relied on the ground operation control system [2].

In recent years, the increasing demand for remote sensing images by various industries and the continuous development of remote sensing technology have created a dramatic increase in the number of remote sensing satellites and have led to a constant

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improvement of satellite functions, giving rise to new problems in satellite mission planning and the implementation process [3]. Multi-satellite and multi-function mission management, planning, uplink control and collaboration methods have imposed higher and higher pressures on ground operation control systems, making the functionality required by ground operation control systems more complex. Therefore, there is an imminent requirement for intelligent implementation of satellite missions to meet the growing needs of satellite users [4].

2 Research Status Review

A surge of research into autonomous management technology took place in the 1990s as the concept of autonomous spacecraft management became popular. Now the United States has successfully applied autonomous management technology in spacecraft such as Deep Space 1(DS-1), Earth Observer 1(EO-1) [5] and Mars Exploration Rovers and space shuttles. The technology has played an important role in guaranteeing the reliability of spacecraft. In comparison, spacecraft in Europe mostly adopt autonomous management technology based on the FDIR system of analytical model and safe mode, such as SMART-1 and SPACEBUS 4000.

In China, autonomous management technology has been studied both in the fields of remote sensing satellites and deep-space exploration. The directed graph method [6] has helped develop algorithm research for on-orbit mission instruction generation, but the logic used in the algorithms is still complex and difficult to realize.

3 Autonomous Mission Management Process

3.1 Definition of Typical Operating Mode

Earth observation missions with remote sensing satellites use imaging and data transmission. The typical operating modes [7] can be defined as follows:

1. Imaging real-time transmission mode: The satellite flies within the visual range of the earth station (visible when the angle of elevation is greater than 5) with a normal flight attitude or side flight attitude, which means that the satellite swings around the motor shaft through a range of angles. After a certain period of stable flight, the payload starts up and starts taking images of the earth [8]. The data processing and transmission system on the satellite implements real-time processing, formatting, channel coding, modulation, amplification and filtering of the observation data and then sends the data to the earth station via a data transmission antenna.
2. Imaging recording mode: The satellite flies through the area of interest with a normal flight or side flight attitude. After a certain period of stable flight, the payload starts up and starts taking images of the earth. The data processing and transmission system on the satellite implements real-time processing and formatting of the observation data. The data is then sent to an on-board data storage unit and transmitted to the earth station at a later stage, when the satellite is flying within the earth station’s visual range.

3. Data transmission mode: The satellite flies within the visual range of the earth station with a normal flight attitude. The data is processed with channel coding and transmitted from the on-board data storage unit to the data transmission RF channel. Modulation, amplification and filtering processes are implemented and the data is sent to the earth station via the data transmission antenna [9].

The direction of data flow under each different operating mode is shown in Fig. 1.

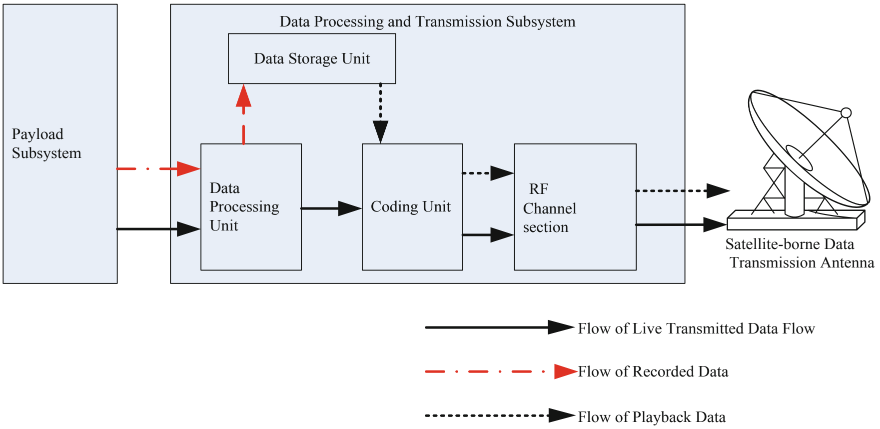

Fig. 1. Direction of data flow under different operating modes

3.2 Implementation Process of Mission Management

The implementation of mission management in remote sensing satellites generally can be divided into scientific planning, mission planning, sequence generation and spacecraft execution, as shown in Fig. 2.

1. Scientific planning

This is usually performed by satellite users based on the requirements of the earth observation mission. The area for the mission is mainly determined based on hot spots, emergency events, resource surveying and mapping requirements.

2. Mission planning

This step is completed by the ground operation control system based on analysis of the scientific planning requirements. Based on the satellite orbit information, weather information, observation target area [10], etc., the scientific planning mission can be translated into an observation mission plan for the particular planning period. Information elements, including the start time of the observation or transmission, the duration, attitude angle and other relevant information for each observation mission, are output to form the mission plan.

3. Sequence generation

The ground operation control system chooses the operating mode for each mission based on the mission plan and observation information elements, and implements the instruction set scheduling and generation for the mode based on the template provided by the satellite provider. The instruction set is composed of several individual instructions and each individual instruction or a combination of several single instructions can control the satellite to fulfil certain functions, such as satellite platform side-sway, data transmission antenna rotation, data processing initialization and camera imaging. Once the instruction set generation is complete, it can be injected into the satellite from the ground control station and satellite control channel.

4. Spacecraft execution

When the satellite receives the instruction set injected from the ground station, each instruction set executes based on its start time and each instruction is executed sequentially. In general, several instruction sets can be executed at the same time.

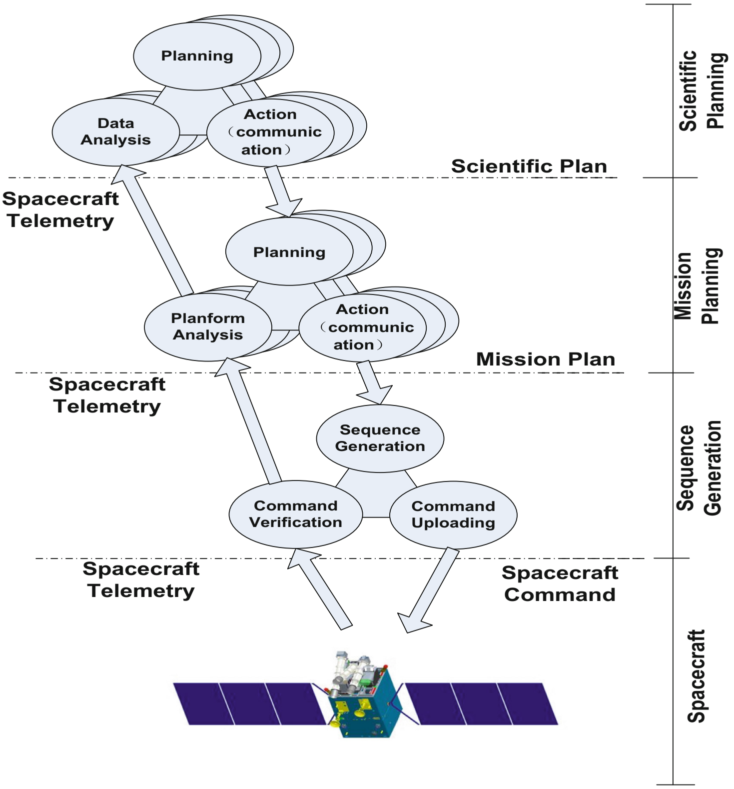

Fig. 2. Typical spacecraft mission management process

This demonstrates that the implementation of the first three processes all need ground control, i.e. mission planning, instruction set generation based on a template and code injection all need to be completed on the ground. This implementation method causes the following problems for users of an on-orbit service:

- As the number of on-orbit satellites increases, users have to undertake a large volume of work related to on-orbit management and planning, meaning that their missions require an increased level of augmentation.
- Instruction scheduling and rule generation are complex processes, and require the instructions to be regularly injected into the satellite. The information interaction process between the satellite and the ground station is tedious and consumes a lot of measurement and control resources.

Optimization of the current operating mode of the satellite is required, and the on-orbit intelligence level also needs to be improved to enhance user experience. Additionally, the interaction process between the satellite and the ground station needs to be simplified, and the user cost needs to be reduced. A spacecraft with autonomous mission management integrates mission planning, sequence generation and instruction implementation into a satellite-borne computer processing mission. The specific process is shown in Fig. 3.

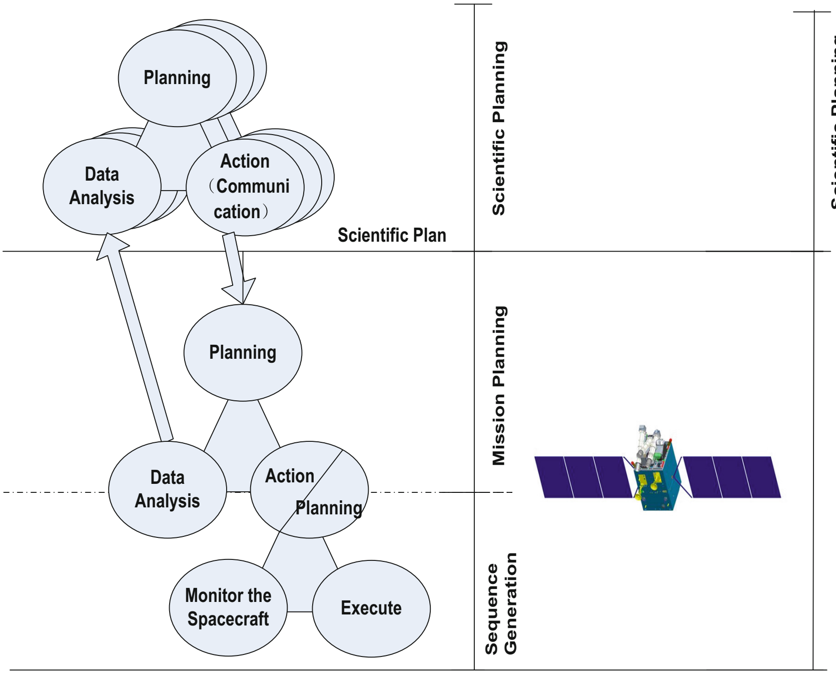

Fig. 3. Spacecraft autonomous mission management process

4 Implementation Strategies for Autonomous Mission Management

The complexity and variability between different operating modes of remote sensing satellites mean that autonomous mission management of spacecraft cannot be expressed as a single algorithm for each data model. Since different remote sensing satellites usually have different operating modes, it is necessary to determine a method which can abstract, simplify and decompose the complex operating modes. Additionally, the complexity of the user interface should be reduced as much as possible to enhance user experience.

A multithread autonomous mission management method is presented in this article that will autonomously manage a spacecraft through three separate processes: mission rationality judgment, mission decoupling and mission instruction generation. This method can transform a complex satellite mission into several simple satellite missions and then process each of these simple missions individually.

4.1 Mission Rationality Judgment

The influence of mission planning on satellite safety should be first taken into consideration, since the process of mission planning is undertaken autonomously by the satellite. In order to ensure that the mission requirements received by the satellite are correct and that the implementation is practical, a mission rationality judgment step is necessary before mission processing by the satellite can commence.

The combination and arrangement of various operating modes have certain constraints, which are set by the satellite design restrictions, and must be satisfied by the planning results. If the constraints cannot be met, the mission plan is determined to be not feasible and re-planning is required. The constraint conditions are as follows:

- The working hours of the load within a given time period should not exceed Tmax.
- The working frequency of the load within a given time period should not exceed Nmax.
- The number of attitude maneuvers within a given time period should not exceed Natt.
- The interval between any two recording missions should be no less than ΔTr (in order to establish and cancel the reserved load imaging state and data transmission record state)
- Any two playback missions should not overlap and the number of playback missions with a continuous interval that is less than ΔTp should be less than two. (Playback missions with a single antenna and a single station and playback missions with double antennas and double stations are allowed; playback missions with double antennas and multiple stations are not.)

The parameters Tmax, Nmax, Natt, ΔTr and ΔTp mentioned above are determined according to the specific requirements of the individual remote sensing satellite.

4.2 Mission Decoupling

Mission decoupling aims to modify and improve the injected mission parameters in combination with the actual execution mode of the satellite. It can control the satellite so that it will execute layer by layer subsequently based on a unified strategy, in order to avoid any conflicts between two individual missions in the implementation process. There are generally two objects that require mission decoupling: the first is the “playback missions with double antennas and double stations” mode, which has a short interval between two data playbacks. The second is the “recording and playback” mode, which means the data recording mode is implemented at the same time as the playback mode.

Mission decoupling is necessary because analysis has found that when a satellite executes recording and playback simultaneously, there may be timing sequence conflicts during the following scenarios:

- The satellite is executing side-sway in preparation for recording while executing the playback mode. If the angle-velocity of the side-sway is too large and exceeds the maximum capability of the angle-velocity of the data transmission antenna, the antenna will not be able to track the ground station effectively.
- Some stand-alone devices for data transmission (such as a data processor and solid-state memory) may have conflicts when switching over between single recording, single playback and recording and playback.
- Some stand-alone devices for data transmission (such as a data processor and solid-state memory) may have instruction conflicts when they are powered up or down during the process of establishing and canceling an operating mode.

As an example of the first point, assume that the satellite executes an attitude maneuver along the X axis, with a capacity of 32°/600 s, and that the curve of the angle and angle-velocity in the attitude maneuver of the X axis is as shown in Fig. 4.

As seen in Fig. 4, the maximum angle-velocity of the X axis under side-sway is approximately 0.15°/s. The angle-velocity of the antenna tracking ground station will be superimposed on the angle-velocity of the X axis. If the side-sway of the whole satellite is not considered, the angle-velocity of antenna X axis in the tracking process is very small, generally no more than 0.05°/s. Based on this, the angle-velocity of the X axis is superimposed and the total angle-velocity is less than 0.2°/s. Now the maximum biaxial rotation capacity of antenna is 1.1°/s, which can satisfy the angle-velocity requirement on tracking the ground station under side-sway. Similarly, it also does not affect the data transmission antenna tracking the ground station during backswing of the whole satellite.

In relation to the second point, when the data processor executes in data recording mode, the internal “AOS routing module” is working, and when it executes in playback mode, the internal “coding module” is working. The two modes can be executed simultaneously or successively without conflict even during mode switchover. The solid-state memory now can realize both recording and playback functions on existing satellites, which is sufficient to maintain an instruction time interval between the two switchovers in the order of seconds.

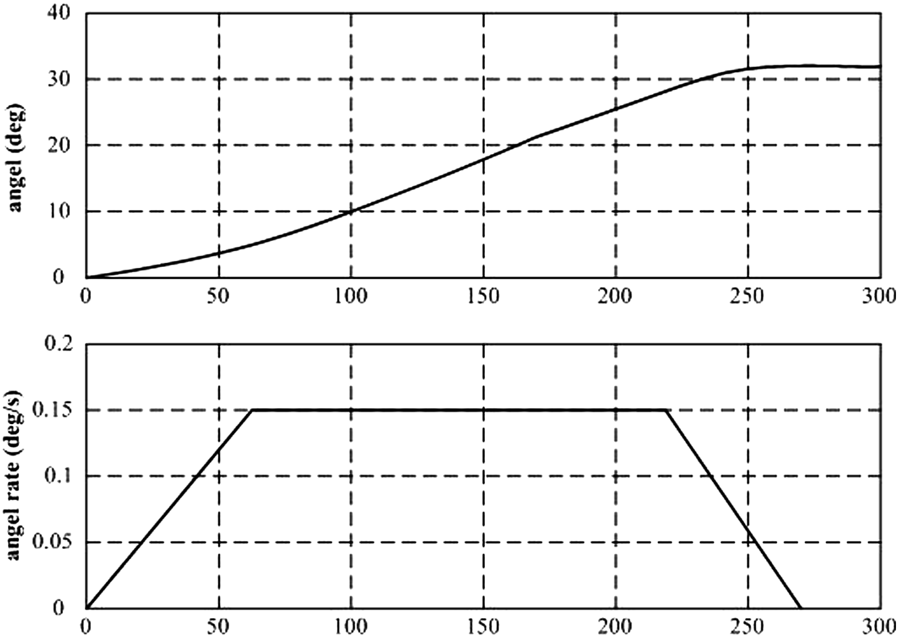

Fig. 4. Angle-velocity curve for satellite under side-sway

For the third point, when the recording and playback overlap, the instructions of the "data processor boot" and the "solid-state memory boot" may be sent repeatedly, but they will not affect the operating state of the subsystem and stand-alone devices. The instructions of "data processor shutdown" and "solid-state memory shutdown" will influence the operating state of the subsystem and the stand-alone devices, and therefore overlapping between the recording and playback states should be identified. If there is an overlap, the last mission should be selected as the target and the instructions of "data processor shutdown" and "solid-state memory shutdown" should be sent.

4.3 Mission Instruction Generation

After mission decoupling, the operating mode can be divided into an "imaging sub-mission" and a "playback sub-mission", which can be combined and arranged into a sequence to realize any complex operating mode. The mission instruction generation actually becomes a combination of a finite number of states. Depending on the design state of different satellite payloads, the corresponding mission instruction sequences of the "imaging sub-mission" and the "playback sub-mission" can be stored in the satellite-borne computer, as shown in Fig. 5. The parameters in the figure can be calculated by the following methods:

- Imaging parameter setting: TgaP = Ts – dTset
- The control unit power up: TonCtrl = Ts – dTset − dTon
- Payload simulator image data unit power up: TonData = TonCtrl + 30
- Payload simulator image data unit power down: ToffData = Te + 1

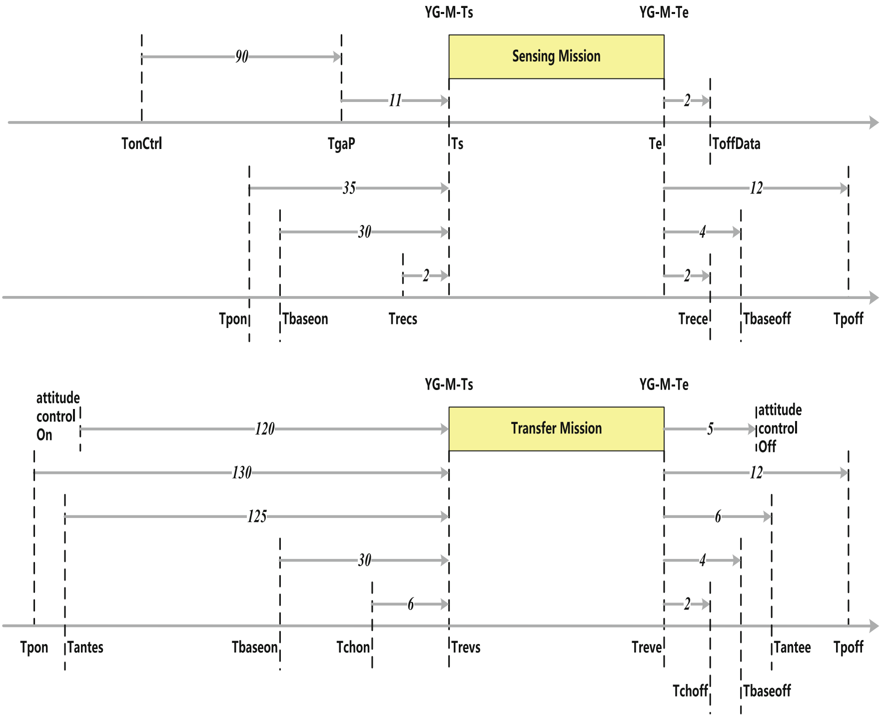

Fig. 5. Timing sequence of instruction sequence generation

Depending on the factors involved in the process of mission decoupling, the sub-mission generating complex mission algorithm will be obtained and the mission instructions will be generated.

5 Application Effect

Traditional satellite mission command block is composed of every commands of on-board equipment.

Table 1. Traditional satellite mission command block

1	Data processing parameter	11	Camera on 3
2	Data processing mode	12	Camera on 4
3	Satellite attitude set	13	Camera off 4
4	Mapping parameter	14	Camera off 3
5	Antenna parameter	15	Camera off 2
6	Antenna on	16	Camera off 1
7	Modulator on	17	Coding unit off
8	Coding unit on	18	Modulator off
9	Camera on 1	19	Antenna off
10	Camera on 2	20	Satellite attitude set

Table 2. Autonomous mission management command block

1	Data processing parameter	4	Time for mapping
2	Data processing mode	5	Mapping parameter
3	Satellite attitude set	6	Antenna parameter

As seen in Tables 1 and 2, Traditional satellite mission command block should be composed of 200 Bytes. Now, satellite users can send only 20 Bytes to complete the same mission by using Autonomous mission management function.

As seen in Table 1, satellite users also need to know how to operate the satellite and the operation steps in traditional satellite mission. Now, only mission parameters are necessary. Therefore, the user's operations are greatly simplified.

6 Conclusions

This article discussed the function and definition of satellite autonomous mission management, based on the traditional mission management mode of remote sensing satellites, and proposed a management method for remote sensing satellites. Our study focused on the implementation strategies of on-orbit autonomous mission rationality judgment, decoupling and instruction generation, and aimed to improve the on-orbit intelligence level and simplify the control and use of satellites. Additionally, it also should reduce ground operation costs and improve the efficiency of on-orbit image acquisition, thus laying the foundation for future satellite-borne mission management designs of mission-oriented intelligent satellites.

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