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Space and Ground Integrated Operation Control for Space Satellite Missions

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Abstract

The existing ground-based satellite management and control cannot fully meet the needs of scientific satellite mission, especially for the future missions. The time, space and information of satellite-ground information transmission are limited to some extent, and the ground needs to grasp the on-board status more fully and timely, and improve the efficiency of satellite control and control effect feedback. The future space science missions' implementation process is more complex, the payload design and detection accuracy is higher, and the operation control accuracy is higher. These characteristics determine the need for the integration of space and ground integration operation control mode.

This paper proposes an integrated management and control method for scientific satellites, which is realized based on the space-based system deployed on the satellite and ground-based system deployed on the ground. The main research contents include: establishing an operation model for integrated management and control of space and ground based on the space exploration tasks of scientific satellites; Based on the request-service mechanism and different intelligence levels of space and ground, the interaction protocol of space and ground control is established. Based on the operation model of integrated management and control autonomous management and control on board is the main method. When necessary, the integrated management and control of space and ground can be realized through the control mode of ground control and according to the interaction protocol of space and ground management and control.

The research of this topic will promote the innovation of space technology and become the starting point of commercial and industrial space operations development. This paper and research, put forward and form a new mode of satellite on-orbit operation management, subverts the traditional existing satellite on-orbit operation management mode, make the satellite on-orbit control more flexible, better able to adapt to the development of new technology of space and ground, greatly advanced the technology of satellite on-orbit operation management, able to adapt to the need of the future of the integration of satellite mission control.

Keywords: (integrated operation, operation control protocol, scientific satellite mission)

Nomenclature

[1]Mission Level: In the uplink control process, the injection from ground to satellite is the TC level data injection, and the content of data injection is the mission requirement. The satellite will schedule and arrange the plan according to the mission requirement.

[2]Event: A sequence of instructions that can be defined in advance to complete a particular activity.

[3]Event Level: In the uplink control process, the injection from ground to satellite refers to a series of events triggered at any time, that is, a list of events with execution time as the trigger condition。

[4]TC Level: In the uplink control process, the injection from ground to satellite refers to a series of data injection triggered at any time。

Acronyms/Abbreviations

[1]Packet Utilization Standard(PUS)

[2]Consultative Committee for Space Data Systems(CCSDS)

[3]APID——Application Process ID(APID)

[4]Tele-Command(TC)

[5]Space Science Mission Operations Center(SMOC)

1. Introduction

Due to the foresight, innovation and complexity of scientific satellite mission, new requirements are put forward for the timeliness of on-orbit operation management. Deep space missions such as gravitational wave detection and space safety-related missions have put forward strong demands for autonomous operation and management in orbit. Therefore, the existing satellite on-orbit operation and control mode based on ground management could no longer meet the needs of scientific satellite mission operation.

The space and ground integrated operation control management and system developed in this project is the basis for ensuring the safe and reliable operation of scientific satellite missions in orbit. After satellite launch, satellite safety, especially the safe and reliable operation of payloads, is the most important task of on-orbit operation management. The only feasible way to achieve this task is through the integrated management and control mode of autonomous control on the space and ground integrated control when necessary.

The research of this paper is the guarantee to ensure the smooth implementation of the satellite project. The on-orbit operation management mode of satellite engineering has always been the main line of satellite engineering in the whole life cycle of satellite engineering from project initiation, scheme design, system development to launch and on-orbit operation management. The research results of this project will provide new and innovative solutions for the on-orbit operation management of satellite engineering, and provide basis for the design of satellite and ground system.

The research of this topic is the key to obtain and improve the scientific output and application value. After the launch of the satellite mission, the acquisition of scientific output and application value depends on the ability of the satellite and payload to efficiently manage the resources on the satellite and carry out rapid mission planning and implementation according to the scientific and application objectives. The research results of this project can provide solutions for efficient operation of satellites in orbit, and ensure the acquisition and promotion of scientific output and application value.

The paper is divided into 6 sections. Section 1 gives the introduction of the article. Section 2 gives the overall design of the research. Section 3 gives the research content and methods. Section 4 gives the research result. Section 5 gives the dicusstion for the future work. Section 6 gives the conclusion of the paper.

2. Overall Design

In order to realize the integrated operation and control mode of space and ground, the overall technical solution is developed as shown in the figure below (see Fig. 1), including four parts: control model, control protocol design, engine system research and development, and prototype demonstration and verification.

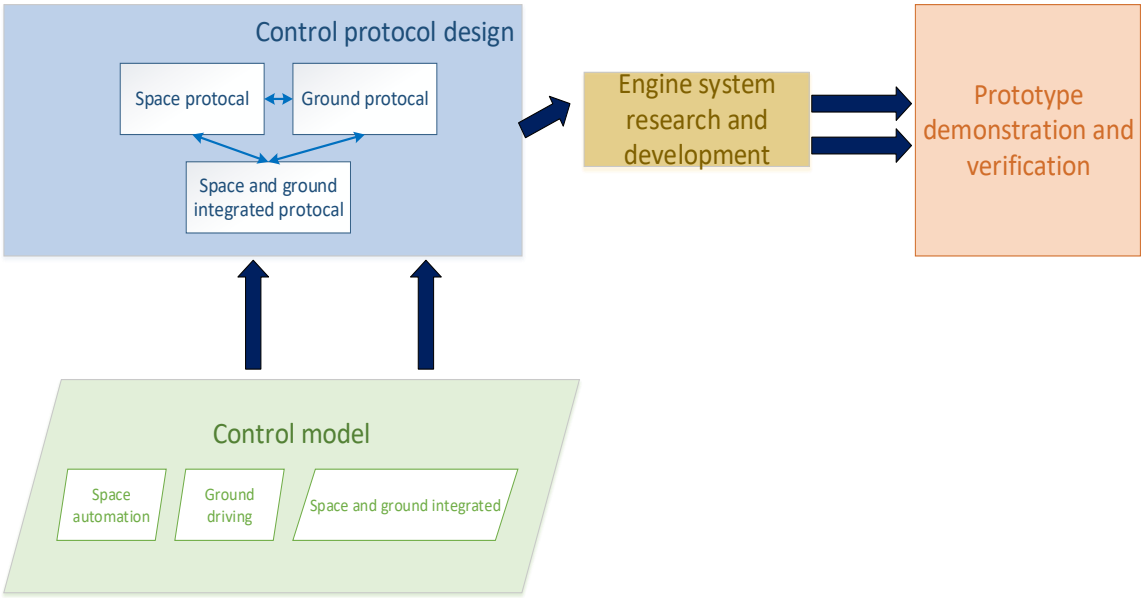

Fig. 1. The overall technical solutions

First of all, research on the control model of space-based integrated satellite management and control, including space-based independent management and control model, ground-based active management and control model, and

space and ground integrated management and control model. It is necessary to define the input, output, interaction attributes and operation of the model.

Then, it is to design the space and ground integrated satellite control protocol, and sort out the space-based control protocol, the ground-based control protocol and the data interaction between space and ground through the abstraction of the model. These three parts need to define certain principles and specifications.

At the same time, the management and control engine system is developed. The management and control engine is designed for the universal system architecture under the three management and control modes of space-based autonomy, ground-based initiative, space and ground integration. Based on the control engine, various control businesses required for satellite on-orbit operation can be realized in any mode, just by tailoring the control engine.

Finally, design and implement a demonstration and verification system to demonstrate the typical control business of space-based, ground-based and space and ground integration, and verify the feasibility of the control protocol and engine.

3. Research Content and Methods

The research content of this subject is divided into four parts, including the research on the business model of space and ground integrated satellite management and control, the design of space and ground integrated satellite management and control protocol, the research and development of the management and control engine system, and the demonstration and verification of satellite space and ground integrated management and control.

3.1 Space and ground integrated satellite control business model

This topic starts from the research of space and ground integrated management and control of satellites, studies the independent management and control business model, the space-based management and control business such as space-based independent resource management, status monitoring and exception handling, exploration task planning, satellite payload control, exploration data management, and studies the space and ground integrated management and control business such as exploration task management, anomaly analysis, satellite payload health management, user service, and carries out the design of each control business model, Thus, the existing satellite on-orbit operation mode based on ground management and control will be gradually developed to the space and ground integrated management and control.

3.2 Design of the control protocol for space and ground integrated operation

The application specification of scientific satellite space and ground integration management and control protocol specifies the application layer protocol used in the space and ground integration on-orbit management and control process of scientific satellite, mainly including the business requirements of space and ground integration, task-level agreement requirements, event-level agreement requirements, command-level agreement requirements, request-service agreement requirements, etc.

This specification is applicable to the on-orbit management and control of scientific satellite spaceflight integration. It is the input and basis for the development of scientific satellite spacecraft and ground operation and control system, and the on-orbit operation management of scientific satellite. The development and on-orbit operation of other satellite spacecraft systems can be implemented by reference.

This agreement refers to relevant domestic and international agreements and standards, including GJB, ECSS and CCSDS. General requirements for the control agreement of space and ground integrated satellite operation:

a) Under the integrated control mode of ground and space, the uplink control data injection intelligent level of ground-based injection is divided into mission-level data injection, event-level data injection and TC-level data injection;

b) Under the integrated control mode of ground and space, both space-based and ground-based can actively send service requests to the other party, and receive and process the request results from the other party to meet the requirements of control tasks;

c) There are two ways to define the uplink remote control package, which can be divided into one layer. CCSDS remote control package and two-layer CCSDS remote control package are respectively defined in this specification.

The space and ground interaction data involved in the control protocol are mainly telemetry data and TC data. The TC package follows the format definition of CCSDS package. The satellite downlink data is the telemetry data packet. The telemetry data packet structure adopts the CCSDS standard format and refers to the PUS protocol of the ECSS standard, and does not involve the satellite-ground transmission frame structure.

3.3 *Research and development of control engine system*

In order to realize and verify the design of the integrated management and control protocol of space and ground, the research and design of the management and control engine system is carried out in this project, mainly including the cooperation protocol engine of space and ground (ground-based part), the cooperation protocol engine of space and ground (space-based part) and the interaction part of ground and space (see Fig. 2).

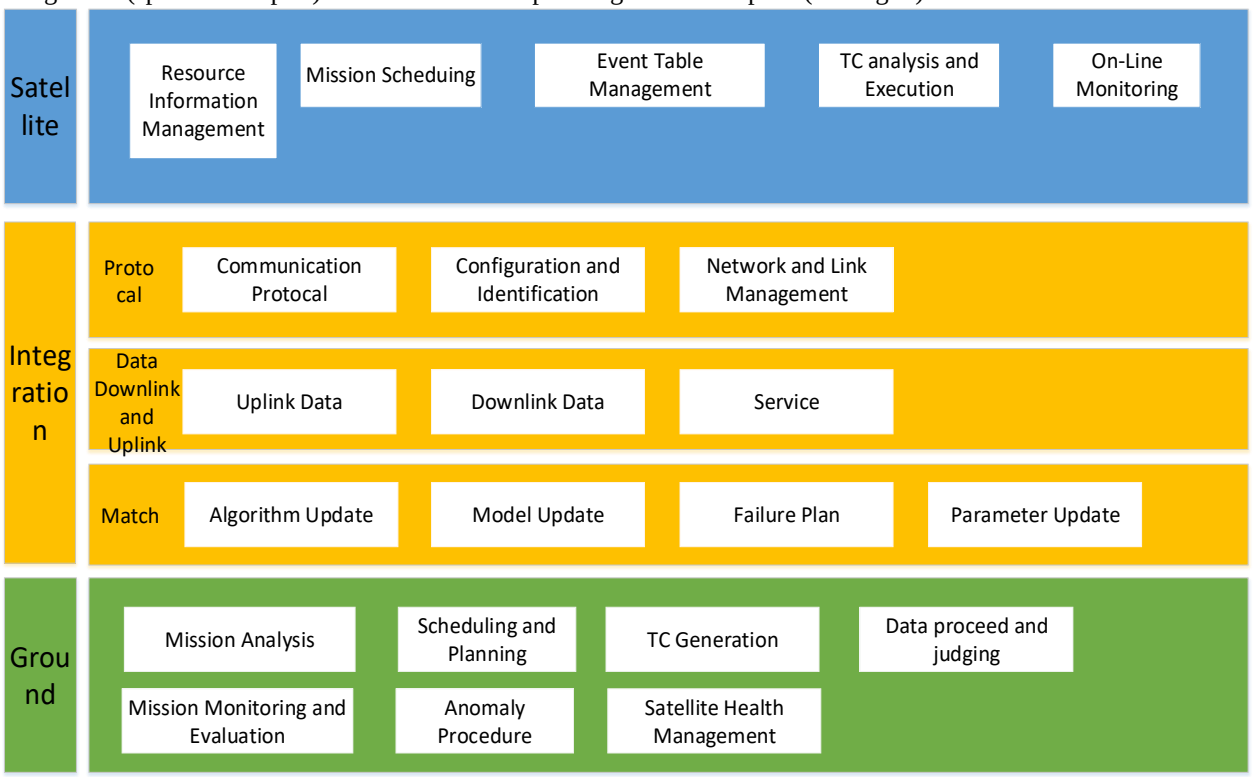

Fig.2. Engine architecture

3.4 Prototype demonstration verification

Build a set of collaborative demonstration and verification system between space and ground;

1) Support the demonstration of three space-based management and control businesses: autonomous resource management, autonomous control and autonomous anomaly handling;

2) Support ground task management, anomaly analysis and diagnosis, emergency response, real-time monitoring, and satellite health management five ground control business demonstrations;

3) Support the analysis and management of space and ground ingerated exploration mission and the business demonstration of payload health management.

The above demonstration and verification contents are analyzed, and the following three specific business scenarios and modes are realized, covering the four control modes of space-based autonomy, ground-based initiative, space-based collaboration and space-based integration, and the verification of service-on-demand control and space-based integration control protocols is realized.

The physical architecture of the space and ground control demonstration system is shown in the figure below (see Fig. 3).

The satellite service simulation software is connected with the load manager via the 1553B bus to send control instructions and receive engineering parameters. The load manager collects simulation data through the RS422 interface, completes the communication with the digital load, and completes the control interface with the commercial camera and turntable to demonstrate the comprehensive demonstration effect of the space-ground control.

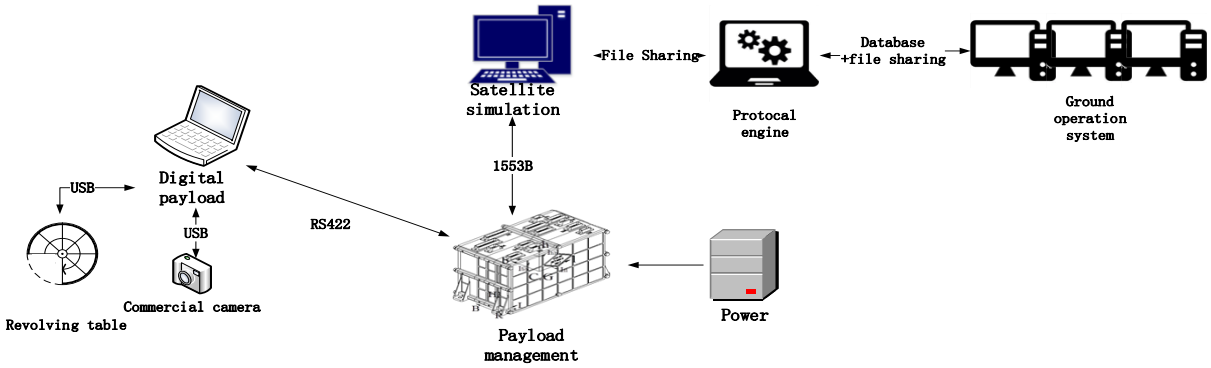

Fig.3. Physical architecture diagram of system

4. Results

The proposed space and ground integrated management and control mode realizes the control uplink control of different intelligent levels. The ground can be injected with space-based executable TC level, event level and mission level data injection, and the space-based can be parsed and executed according to the intelligent capabilities of different levels and on-board independent management and control. The designed service based on PUS protocol - on-demand space and ground integrated satellite control mode provides users with satellite use mode based on control engine. Realize the control protocol of the integration of space and ground , the interconnection and interworking of protocols, the consistency of data uplink and downlink and configuration, and the coordination and interaction between space and ground.

Uplink control collaboration mode: according to the different levels of ground intelligence design (mission level/event level/TC level), the ground completes the data injection generation of mission level (task information), event level (event table) and TC level respectively, and the space base completes the instruction parsing and execution according to different levels.

Downlink control cooperation mode: according to the different levels of implementation of space-based online monitoring (online monitoring and control/online monitoring), the ground-based completion of exception handling and command generation or the ground-based completion of the management of space-based feedback processing results.

5. Discussion

The scientific satellite missions that may be set up in the future include many scientific fields, such as space astronomy, solar-terrestrial space, planetary exploration, and the earth environment. The scientific objectives of each mission are leading internationally, innovative, and of great scientific significance. These scientific satellite missions have higher requirements for the accuracy of platforms and loads, as well as the refinement of satellite operation and control. At the same time, the on-orbit working mode is complex, the load working mode is diverse, and the modes of multi-load cooperation, multi-satellite cooperation and satellite-ground cooperation are also included. The management and control mode of space-earth cooperation and the space-earth integration management and control agreement studied in the project can be partially realized in supporting the operation and control management of future scientific satellite missions, and strengthening the ability of space and ground mission coordination.

6. Conclusions

The space and ground integrated management and control model studied could better adapt to the forward-looking, innovative and complex characteristics of future scientific satellite engineering tasks, especially the limit requirements of future scientific satellite missions on the timeliness of on-orbit operation management, and the strong demand of deep space missions such as gravitational wave detection and other space safety-related tasks on satellite autonomous operation management, to meet the needs of future scientific satellite engineering, At the same time, it helps to determine the on-orbit mode of future scientific satellite engineering.

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