Application of Artificial Intelligence in the Planning of Navigation Satellite in Orbit Reconstruction Tasks

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Abstract. The basic system of Beidou-3 has been completed and started to provide global services so far. This system is composed of 24MEO+3GEO+3IGSO, and 80% of products have refactoring functions. In view of the potential load function upgrade needs in the future, as well as the reliability upgrade and maintenance of the system, there is a need for the reconstruction of the entire network of satellites in orbit. Analyze the characteristics of the three types of satellites and break through the traditional reconstruction schemes. Most of them are reconstructed through the ground measurement and control and operation control channels. The speed is low and the timeliness is poor. A new reconstruction idea is proposed, and the IGSO satellite Ka high-speed ground link is used to transfer the program. Make a bet, and then distribute the reconstructed data through the laser inter-satellite link. According to the Beidou satellite's full-satellite redundant backup feature, the three types of satellite mission characteristics are learned through artificial intelligence, and the redundant satellites are met while meeting the positioning requirements. Performing reconstruction upgrades, this method can greatly improve the timeliness of reconstruction and shorten the impact on the system's service performance interruption.

Keywords: Artificial intelligence · On-orbit reconstruction · Mission planning

1 Introduction

In December 2018, the basic system of Beidou-3 completed the construction and began to provide global services, following the development law of navigation system construction, following the incremental thinking, solidifying the engineering technology status in stages, and the key software has the ability to be flexible, reconfigurable and expandable on orbit. At present, 80% of spaceborne stand-alone aircraft have reconfigurable functions. Whether it is software upgrades for a better user experience or software upgrades for system maintenance, it involves the upgrade of a large number of satellites. At present, most of the on-orbit reconstruction schemes are carried out from the operation control/measurement control channel through the L/S frequency band. The above note is that the timeliness is poor. The upload time of the FPGA configuration data for 1 piece of 5.5 million gates is about 600 min [3]. Every system upgrade is faced with a

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reconstruction task of 30 satellites, which will greatly affect the system. The continuity of the orbit service, therefore, it is urgent to find a time-efficient reconstruction plan in the system upgrade, and it is necessary to plan the reconstruction task of 30 satellites according to the working status of the satellites.

2 Path of Transmission in Reconstruction

On-orbit reconstruction is a process in which the on-ground injection system transmits configuration data to the spacecraft in a certain format through a wireless channel, and then is parsed by the spacecraft's remote receiving device and sent to the FPGA module that needs to be reconstructed. The process is mainly composed of three parts: the uplink injection station that reconstructs the configuration file, the device that receives and parses the reconstructed configuration file, and the reconfigurable target FPGA; the transmission process can be divided into two stages, the first stage is The satellite-to-ground transmission phase, that is, how to ensure that the configuration file is quickly and reliably uploaded from the injection station to the remote analysis device. The second stage is the intra-satellite transmission stage, that is, how the file is transferred from the remote analysis device to the FPGA module that needs to be reconstructed [3]. The influencing factors of the reliability and timeliness of transmission in these two stages are specifically analyzed, and the focus is on how to realize the rapid reconstruction of the entire constellation.

2.1 Satellite-To-Earth Transmission

Currently available transmission channels are: ground measurement and control, operation and control channels, business channels and dedicated channels.

1) Ground measurement and control, operation control channel
   The ground-based measurement and control channel is independent of the application of the satellite's payload, ensuring that the satellite is always in a controllable state. However, the current measurement and control channel mostly uses the S-band for betting, and the transmission rate is relatively low and the transmission time will be relatively long. The amount of configuration data is generally relatively large. Regardless of the resource consumption of the program preparation phase and the program reloading process, only the transmission speed is considered, and the engineering cost of performing a reconstruction is very large. To solve this problem, a certain algorithm can be used to compress the configuration file. The mainstream compression algorithms currently available include arithmetic coding, Huffman coding, and dictionary-based LZ series compression algorithms [4, 6], which will inevitably reduce its reliability during the compression process., Reduce the bit error rate.
2) Business channel
   The configuration file that needs to be reconstructed is transmitted through the service channel, the configuration data and the remote control command are combined, and the "enter reconstruction state" is sent through the remote control command chain

to start the reconstruction function. Since the communication channel has a certain communication error rate limit, once the program has an error code, it cannot be loaded normally, which will inevitably affect the communication interruption of the service channel.

3) Dedicated channel
Using an independent dedicated channel, the channel supports a higher transmission rate, is independent of business instructions and measurement and control instructions, has less interference, high rate and high reliability.

2.2 Intra-satellite Transmission

After the ground remote control sending center formats the configuration data, it is packaged by the remote control communication protocol and sent to the satellite, it also needs to be transmitted within the satellite. It mainly includes three aspects: 1) Data distribution process: the spacecraft remote control receiving device parses it and gives the correct configuration data, and distributes it to the next-level processing unit according to the extracted target processor ID. 2) Data loading process: The control processing unit writes the configuration data to the configuration register (DSP or FPGA) through a dedicated configuration interface. 3) Result feedback: After the processing module configuration is loaded, the configuration result identification will be returned. Finally, the interface processing unit feeds back the configuration and loading status information and other tasks, and completes the information interaction with the dedicated ground station system.

Due to the different positions of the FPGA that needs to be reconstructed in the spaceborne system, the transmission path is also different. The configuration bus used in the spacecraft is generally 1553B bus, RS422 bus, LVDS bus and high-speed data transmission TLK2711 bus. The maximum transmission rate of 1553B bus is 1Mb/s, and the maximum transmission rate of RS422 bus is 10Mb/s. The transmission rate of LVDS bus is: 10 Mb/s–1 Gb/s (recommended maximum 655 Mbps), TLK2711 bus 1.6Gb/s–2.7 Gb/s. In order to ensure the effectiveness of the transmission, in the long-term reconstruction process, if there is an error in the transmission, it needs to be reconstructed again. For this reason, the configuration file will be formatted in sections in the system design, and all the correct points will be received on the satellite. After the segment data, the overall configuration file assembly and storage are finally completed in the spacecraft. In the system design, the EDAC check is performed in segments, and the telemetry of whether the reception is correct or not is provided in the segmented data, and the data blocks with transmission errors can be reconstructed separately. In addition, the system design has also designed the “Breakpoint Resume” function. Once a power failure occurs, the data that has been noted is valid, and it will be continuously transmitted from the breakpoint when the power is turned on again.

In terms of reliability, the configuration data is stored on the satellite for operations such as the configuration of reconfigurable FPGAs, reloading after power-off reset, and SEU refresh prevention. Its correctness is critical. For long-life spacecraft, long-term storage of data generally requires anti-radiation design and reliability design measures to ensure data availability. On the one hand, the reliability and radiation resistance of the memory chip must meet the requirements, and non-volatile memory such as EEPROM and Flash is generally selected. On the other hand, it is necessary to deal with the single event flip effect that occurs in the space environment and generate data on the memory. There are two common methods for error-tolerant design: Error Detection And Correction (EDAC) and Trip Module Redundancy (TMR) + regular refresh [7].

3 New Type of Navigation Satellite On-Orbit Reconstruction

The Beidou-3 satellite navigation system is composed of 24MEO+3GEO+3IGSO satellites. Its constellation is shown in Fig. 1. All three types of satellites have basic navigation loads, Ka inter-satellite links and laser inter-satellite links, which can pass through each other. The inter-satellite link is built with the characteristics of "one satellite connects to all Netcom". Among them, IGSO satellites have their unique services, namely Ka high-speed ground link and Ka high-speed ground link. 300 M/bps. The betting rate is fast, the reliability is strong, and the timeliness is good.

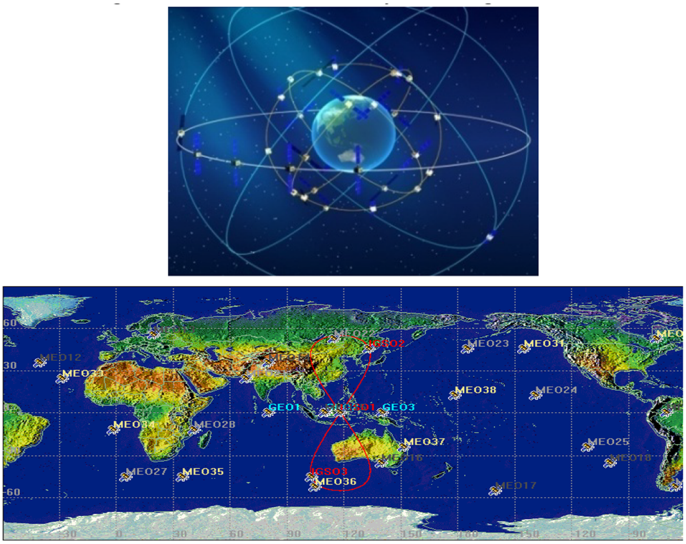

Fig. 1. The constellation composition and sub-satellite trajectory diagram of BDS-3 navigation system

According to the characteristics of the three types of satellites of the Beidou system, an on-orbit reconstruction scheme is proposed. The scheme is based on the IGSO satellite with large-capacity data storage space and the high-speed ground link load with Ka-band to achieve a large number of laser inter-satellite links. The characteristics of the satellite-to-ground high-speed uplink and downlink transmission of data. On the one hand, the satellite-to-ground high-speed link is used as the channel for program reconstruction. On the other hand, the satellite adopts a local dynamic reconstruction scheme. Without affecting other FPGA areas, the FPGA automatically rebuilds a pre-defined area. Configuration. The block diagram of the reconstruction principle is as follows: complete the annotation, verification and file integrity check of the reconstruction program, and give the corresponding response to the corresponding FPGA. The EDAC check bit should be added to the data written in FLASH to improve the reliability of data storage, and it can read back and check the reconstructed files on the note. The reconfiguration refresh control FPGA uses ACTEL's anti-fuse FPGA. The reconstructed program is uploaded at high speed through Ka high-speed ground link, and then the reconstructed program is distributed through the laser inter-satellite link (Fig. 2).

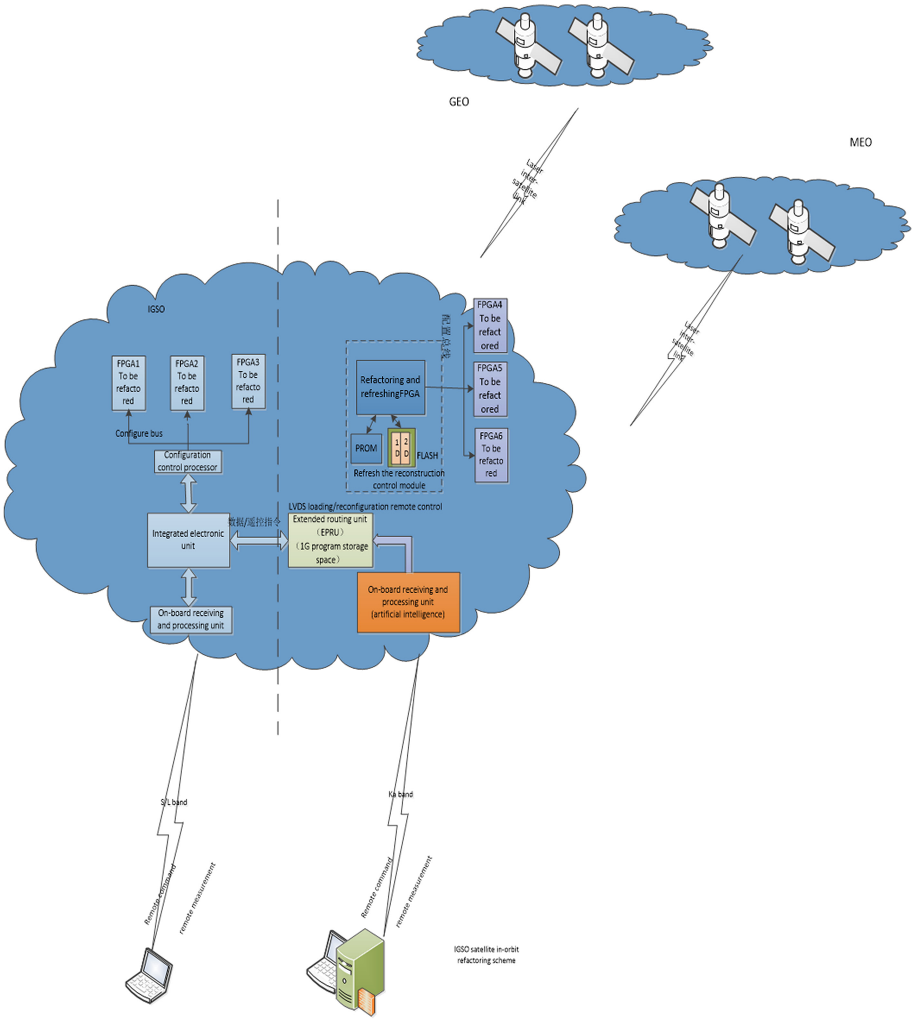

Fig. 2. New on-orbit reconstruction scheme

Program loading is controlled by ACTEL FPGA. The same programs are stored in Zone 1 and Zone 2 as mutual backup to improve the reliability of on-track. The left side of the figure is the traditional reconstruction scheme, which only supports independent reconstruction of one satellite by one star, and the right side is the new reconstruction scheme, which can make full use of the "resumed transmission" function to carry out the whole network satellite when the satellite is idle Refactoring.

On-board receiving and processing unit: receiving remote control information sent by the ground station, receiving uplink configuration data, real-time monitoring of configuration loading status information fed back by the interface processing unit, and completing the information interaction with the dedicated ground station system, and receiving through the ground The status and mission information of other satellites, the information after intelligent processing on the ground, interact with the satellites, and plan reconstruction tasks by learning the status of other satellites.

Extended routing unit: It has a large-capacity storage capacity (1T), which is used to store the data of the laser inter-satellite link, and the space used to store the program is 1G. It mainly completes the verification, analysis, and distribution of configuration data, and sends the correct configuration data frame to the corresponding processor for configuration loading according to the extracted frame type, target processor ID and other identification information.

Refresh control module: complete the power-on configuration and online reconfiguration of the subband exchange FPGA, where the online reconfiguration is determined by the corresponding remote control command. After the configuration is successfully completed, switch to refresh mode, and refresh the subband switching FPGA periodically, with a refresh cycle of 3.5 min $\pm$ 30 s (5 MHz working clock). The configuration refresh program includes the default program (prom) and the reconstruction program (flash). The mode selection is determined by the corresponding remote control command.

4 Application of Artificial Intelligence in Reconstruction Task Planning

The ground station classifies and preprocesses the telemetry information transmitted by the satellite, performs statistics on the information attributes, establishes a model, and initially learns and memorizes it. Then, according to the changes of external factors, it collects the change information of the satellite, and through in-depth analysis, Find the most relevant characteristic indicators and human factors related to the target, form an in-depth understanding of the mission of each satellite, and form a corresponding decision-making system. The decision-making system is combined with the intelligent decision-making model library formed in the previous design process to form According to the decision report under the current situation, the mission characteristics of the satellites are identified. As the Beidou satellite system achieves more than 6-fold coverage worldwide, it forms a backup relationship with each other on the premise of meeting the positioning requirements. The topological structure of the satellite is performed through artificial intelligence. In planning, the satellites that need to be reconstructed are scheduled at the right time, and reconstructed to reduce the interruption of service continuity and do not affect the use of users (Fig. 3).

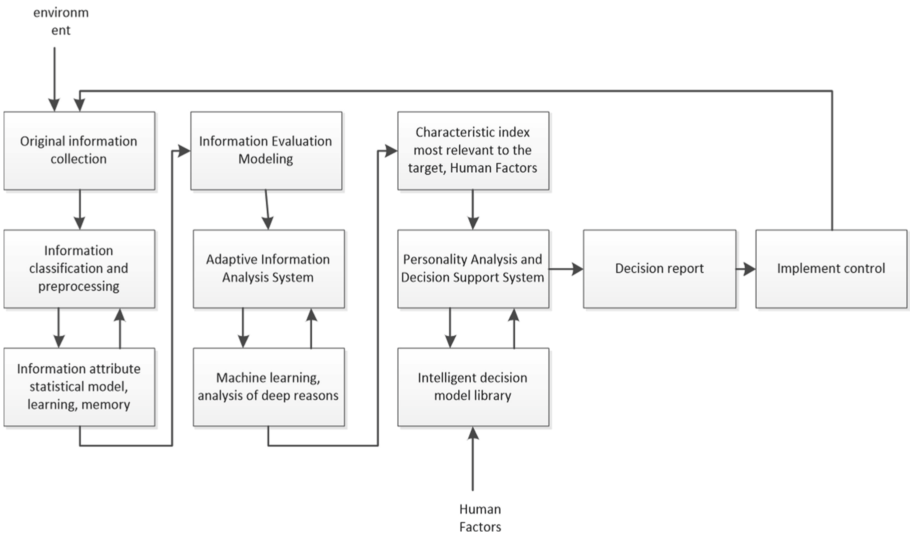

Fig. 3. Application process of artificial intelligence in reconstruction mission planning

5 Verification and Conclusion

In order to verify the reliability and timeliness of the Ka-to-ground link, the engineering test was performed on the ground space by simulating the on-orbit state, and the on-board reconfigurable FPGA was reconstructed. Among them, the upload speed of the Ka-band link is 300 Mbps, and the satellite receiving processing unit receives the configuration data and distributes it to the extended routing unit. The extended routing unit distributes to each module using the LVDS bus, and the designed transmission speed is 20 M/s (Table 1).

Table 1. Statistics of configuration data scale and transmission time of FPGA under different schemes

Serial number	FPGA model	FPGA scale	Configuration data volume/bit	Storage space/Mbit	Transmission time of raditional solution (rate is 4 kbit/s)	Transmission time of the new scheme (rate is 300 Mbit/s)
1	XQ2VR3000	3 million gate	10494368	16	2900	10
2	XQR4VSX55	5.5 million gate	22744832	32	6000	25
3	XC5VFX130T	13 million gate	49234944	49	13000	43

The traditional reconstruction scheme is injected through the uplink S measurement and control\operation control channel. For larger programs, the satellite-to-ground transmission rate limits the timeliness of reconstruction. The Beidou global networking system has been completed. Once needed On-orbit reconstruction requires a lot of time and interrupts the continuity of on-orbit services. The Ka dedicated channel is designed for betting, which can effectively improve the timeliness of betting, and for this star, betting can be completed in minutes. In addition, the on-board program adopts dual backup storage mode, and is equipped with a regular refresh function. The on-board program is refreshed with a 3.5 s refresh cycle, which improves the reliability of the program on orbit, and the timeliness of uploading is greatly improved compared with the traditional reconstruction scheme.. Using artificial intelligence to learn the current state of the satellites, find the operating characteristics between the three types of satellites, and plan out the corresponding reconstruction plan. When the system is upgraded, the impact on the continuity of satellite services is shortened as much as possible. duration.

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