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Payload health monitoring and management platform for space scientific satellite operation

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Abstract

Scientific satellite will face many unknown risks in orbit because of its special operating environment and complex structure. Especially, as an important part of the scientific satellite, payloads are likely to cause inestimable losses if they fail. Therefore, it is particularly important to carry out payload health monitoring and management for scientific satellite, which is of great significance to increase the safety of scientific satellite on-orbit operation, reduce the cost of ground operation control, and ensure the implementation of scientific satellite missions. At present, the handling process of payload failures and anomalies is still based on manual intervention. With the development of computer technology, big data technology and artificial intelligence technology, more possibilities are provided for payload health monitoring and management. A payload health monitoring and management platform for space scientific satellite operation is designed in this paper, which can provide scientific research users and satellite operators with support for satellite operation information management, payload knowledge discovery, and payload fault diagnosis, payload health analysis and prediction. The logic architecture design and integrated workflow design of the prototype system of the platform are introduced, and the application scenarios and usage patterns of the platform are summarized in this paper. The platform adopts the layered design of data, algorithm, model, and application. Based on the technology platform, it realizes the application of payload on-orbit operation status and trend analysis, and improves the depth and comprehensiveness of space scientific satellite on-orbit operation control. As a general platform, we successfully applied our platform to Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor (GECAM) satellite, which provided valuable information for understanding payload health and inferring the cause of parameter anomalies. The payload health monitoring and management platform for space scientific satellite operation is extensible, and algorithms and models for health monitoring, management and analysis can be incorporated into the platform, and a broader technical and application research can be carried out based on this platform.

Keywords: science satellite; payload; fault diagnosis; health management; platform design

Nomenclature

AI: Artificial Intelligence

Acronyms/Abbreviations

DAMPE: Dark Matter Particle Explorer
GECAM: Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor
ASO-S: Advanced Space-based Solar Observatory

1. Introduction

With the implementation of the Space Science Exploration Program and various pilot projects for space exploration, more and more space science satellites have been established and launched, including the Dark Matter Particle Explorer (DAMPE) Satellite, Shijian-10 Satellite, Micius Satellite for Quantum Science Experiments, Hard X-ray Modulation Telescope Satellite, Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor (GECAM) Satellite, Advanced Space-based Solar Observatory (ASO-S) Satellite and so on. Space science is of great significance to China's implementation of the innovation-driven development strategy. Space science satellites are different, do not repeat production, constantly put forward new demands, and continue to provide new vitality for the high-tech space strategy. Once a scientific satellite fails, it will cause huge losses. Therefore, it is necessary to detect anomalies and faults in the operation of the satellite in time [1, 2].

Payload health monitoring management is an important part of satellite rescue. At present, the disposal process of payload faults and anomalies is still based on manual intervention, and the operation status of satellite platform and

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payload is monitored mainly through satellite downlink data. Once anomalies are found, only experienced professionals can locate faults [3, 4]. Its disposal is mainly ensured by the fault disposal plan formulated in advance. Due to the complex system architecture of the satellite itself and the diverse design of the payload, this disposal method is difficult to achieve the optimization of the disposal effect. With the development of computer technology, big data technology and artificial intelligence technology, more possibilities are provided for payload health monitoring and management [5, 6, 7]. The research and design of payload health monitoring and management platform for space scientific satellite operation is of great significance to increase the safety of space scientific satellite in orbit, reduce the cost of ground operation and control, and ensure the implementation of space scientific satellite missions [8, 9, 10].

2. Functional composition of payload health monitoring and management platform

A payload health monitoring and management platform for space scientific satellite operation could provide scientific research users and satellite operators with support for satellite operation information management, payload knowledge discovery, and payload fault diagnosis, payload health analysis and prediction, as shown in Fig. 1.

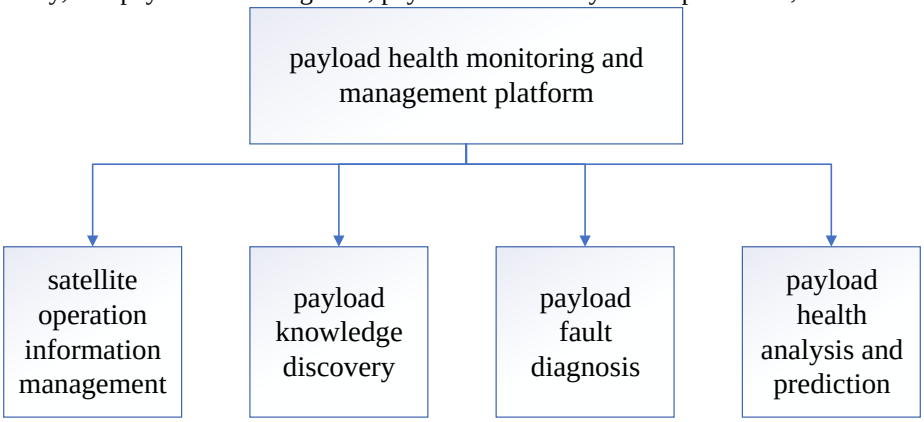

Fig. 1. Functional composition diagram of payload health monitoring and management platform

The satellite operation information management can provide unified management and data services for the whole life cycle data, including orbit attitude data, plan and command data, engineering telemetry parameter data, orbit related operation control data and space environment data, as well as static knowledge information such as payload mechanism and failure plan during satellite in-orbit operation.

The payload knowledge discovery can carry out correlation analysis on the whole life cycle data, excavates the potential correlation between different data contents, and establishes the basic algorithm and model library. It provides basic models for payload fault diagnosis and payload health analysis and prediction.

The payload fault diagnosis can construct the payload failure model, build, and maintain the payload failure model library. The payload fault model is used to analyse and reason the payload parameter data, which provides a support platform for finding and locating the fault points and possible fault causes.

The payload health analysis and prediction can evaluate the current operation of each payload, analyse the in-orbit performance of the payload, and predict its health status through continuous monitoring of the health status of the payload.

3. Prototype system design of the platform

3.1 Logic architecture design

The payload health monitoring and management platform for space scientific satellite operation is divided into five layers from the bottom up, including the hardware equipment layer, the data layer, the algorithm layer, the model layer, and the application layer.

The hardware equipment layer is the lowest layer of the system logical architecture. Network devices, storage devices, servers, and workstations are used to build the necessary hardware environment for system operation.

The data layer includes the full life-cycle payload housekeeping data, engineering data, control data, space environment data and other real data, as well as static knowledge information such as payload mechanism and failure plan.

The algorithm layer includes data processing algorithm, feature extraction algorithm, trend prediction algorithm, anomaly detection algorithm, association rule algorithm and other common machine learning algorithms. It has a general interface to provide algorithm support for the model layer.

The model layer provides the basic application model for the application layer, including the payload fault diagnosis model and the payload health trend prediction model.

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The application layer is a window for business display and human-computer interaction. In addition to managing all data, knowledge, algorithms, and models, it also provides model training services, fault diagnosis services, health analysis and prediction services.

The logic architecture design of the payload health monitoring and management platform is shown in Fig. 2.

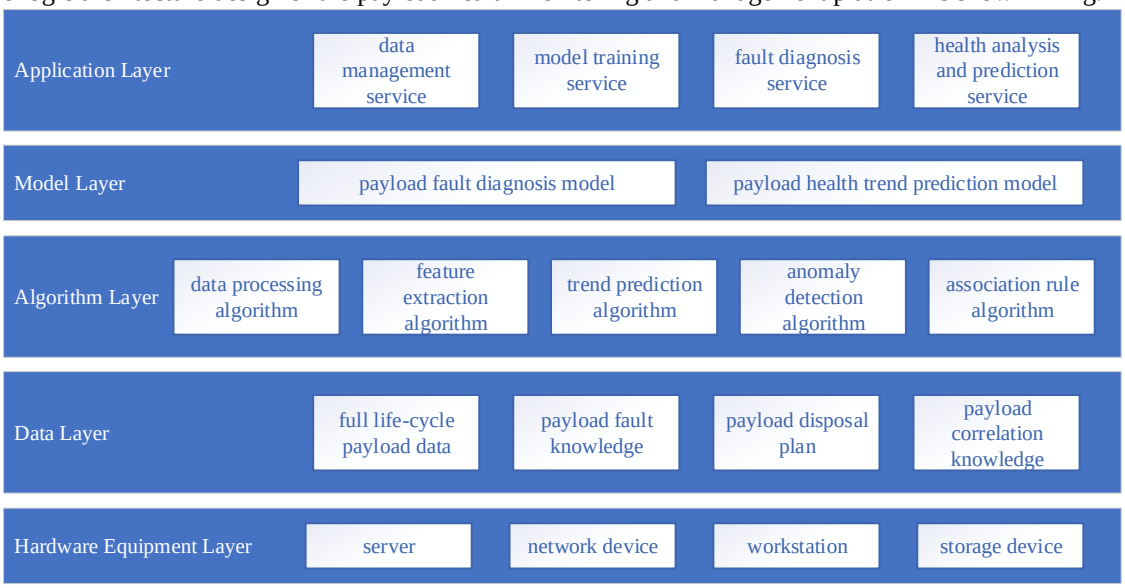

Fig. 2. Logic architecture diagram of payload health monitoring and management platform

3.2 Integrated workflow design

The integrated workflow design of the payload health monitoring and management platform is shown in Fig. 3.

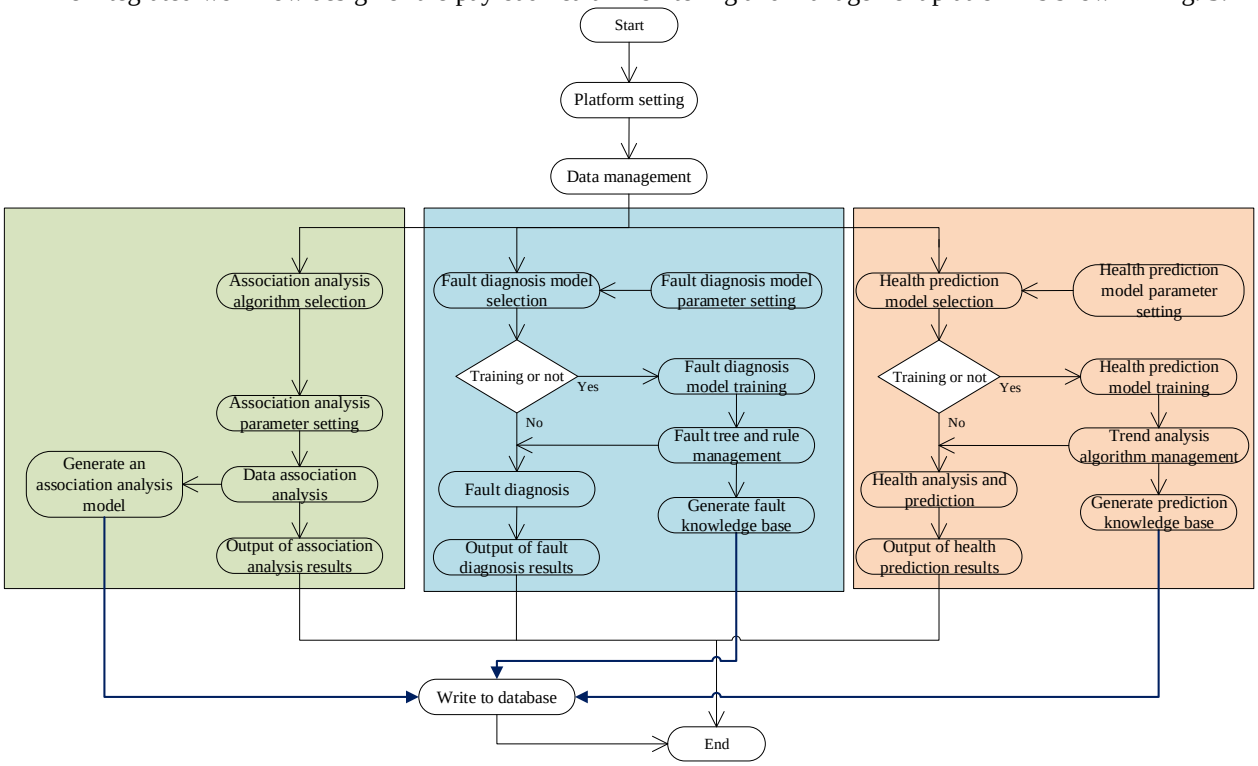

Fig. 3. Integrated workflow diagram of payload health monitoring and management platform

Payload health monitoring and management platform provides data services of satellite operation information based on the real life-cycle data of scientific satellite, such as payload housekeeping data, control data and space environment data, as well as static knowledge information, such as payload mechanism and fault recovery strategy. Applying expert knowledge and artificial intelligence technology, a comprehensive analysis is carried out on the

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relationship between the payload parameters data and the relationship between the payload data and space environmental events, and the associated knowledge base is constructed. Common machine learning algorithms are built into the platform with common interfaces to provide algorithm support for model training, such as data processing algorithm, feature extraction algorithm, association rule algorithm, anomaly detection algorithm and trend prediction algorithm. Algorithms are trained on datasets to generate models for payload fault diagnosis and payload health analysis and prediction. Through various types of normal or abnormal payload data, payload mechanism and fault recovery strategy, the associated knowledge base is used to detect payload anomalies. When there is an anomaly, the payload fault diagnosis model is used to diagnose the fault, and the fault diagnosis result is output. Based on the payload operation data and payload health analysis and prediction model, the operating conditions of each scientific satellite payload are analysed and predicted, and the predicted results are output.

4. Application scenario and usage pattern

During the operation of the scientific satellite in orbit, the payload health monitoring and management platform for the space scientific satellite can be deployed on the graphics workstation in the space science mission hall and the integrated operation and management room, and query and display the data, status, abnormalities, and health status prediction of the payload through multi-screen or large screen projection. It makes the scientific satellite mission operators have an intuitive understanding of the current overall operation status of the payload and the problems that appear, and assists operators to analyse these abnormal situations.

The payload health monitoring and management platform for the space scientific satellite operation supports users to configure models, algorithms, and parameters according to their requirements, call the model in the model management library to diagnose the configured payload data, and output the payload health state prediction results according to the configuration requirements, which is convenient for operators to quickly locate and diagnose the fault. And the operation condition of each payload is analysed and predicted.

As a general platform, we successfully applied our platform to Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor (GECAM) satellite, which provided valuable information for understanding payload health and inferring the cause of parameter anomalies. The payload health monitoring and management platform for space scientific satellite operation is extensible, and algorithms and models for health monitoring, management and analysis can be incorporated into the platform, and a broader technical and application research can be carried out based on this platform.

5. Conclusions

The importance of payload health monitoring and management for space scientific satellite operation has attracted increasing attention. In order to meet the needs of scientific satellite payload health monitoring and management, this paper constructs a payload health monitoring and management platform for space scientific satellite operation, which could provide scientific users and operators with support for satellite operation information management, payload knowledge discovery, and payload fault diagnosis, payload health analysis and prediction. Aiming at the scientific satellite payload health monitoring and management platform prototype system, this paper designs the logical system architecture and integrated workflow. This paper introduces the application scenario of the platform, which is necessary for the research and design of payload health monitoring and management for space scientific satellite operation.

Acknowledgements

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