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Design of Orbit-Ground Closed Loop PHM System for Spacecraft

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***Abstract*—The technologies of spacecraft Prognostics and Health Management (PHM) are researched from the architecture and communication protocol. Firstly the spacecraft PHM system is proposed to build with the mode of orbit-ground coordination three-level closed loop. Then, the communication protocol of PHM for spacecraft is designed.**

Keyword—prognostics and health management; spacecraft; architecture

I. INTRODUCTION

As the flight mission of spacecraft is highly complex and with bad operating environment, which requires high reliability and safety of the system, real-time monitoring, early warning and autonomous intelligent management will be the mainstream development direction of future spacecraft. Prognostics and Health Management (PHM) is a general technology that evaluates the current health status, determines the time of future failure, and calculates the effective life span according to the historical state and environmental factors of the system in order to reduce the risk of system failure and ensure the reliability[1]. PHM systems generally need to complete the functions of fault detection, fault identification and isolation, fault prediction, health assessment and decision-making recommendations[1].

In this paper, the spacecraft PHM architecture of orbit-ground closed-loop and the key technologies of each functional level are summarized.

II. THE DESIGN OF SPACECRAFT PHM ARCHITECTURE

With the application of PHM technology in aerospace, vehicle engineering and other industrial fields, different types of PHM systems have emerged, but their basic ideas and principles are similar, that is, through hierarchical information processing methods, useful information of monitoring objects is gradually extracted to complete fault prediction and decision-making reasoning for complex systems. The logical hierarchical health management system structure proposed by Boeing is the basic idea of PHM top-level design[2]. Open System Architecture for Condition Based Maintenance (OSA-CBM), based and developed on that system, has been applied in the industry of American warship system, civil vehicle and so on[3][].

PHM technology based on on-condition maintenance is built on the basis of mature testability design, especially the development of Built-in Test (BIT) technology, which makes comprehensive diagnosis and health management possible. The current level of spacecraft testability design and self-test is not high, which makes it difficult to complete on-board autonomous health management, due to the limited number of test points and sensors constrained by the spacecraft weight and the more complex, unknown space environment. Therefore, we construct the satellite PHM system by adopting the orbit-ground coordination three-level closed-loop working mode, to better support the satellite in-orbit health management.

A. Spacecraft PHM System of Orbit-ground Coordination Three-level Closed-loop

As shown in Figure I, the satellite PHM system is composed of two parts, on-board and on-ground, which cooperate to complete the task of satellite fault prediction and health management. The lower half of the diagram shows the on-board PHM system, which is responsible for information collection, fault diagnosis and short-term fault prediction and other autonomous health management; the upper half represents the ground PHM system, which is responsible for long-term or complex fault prediction work, and requires ground equipment and manual assistance.

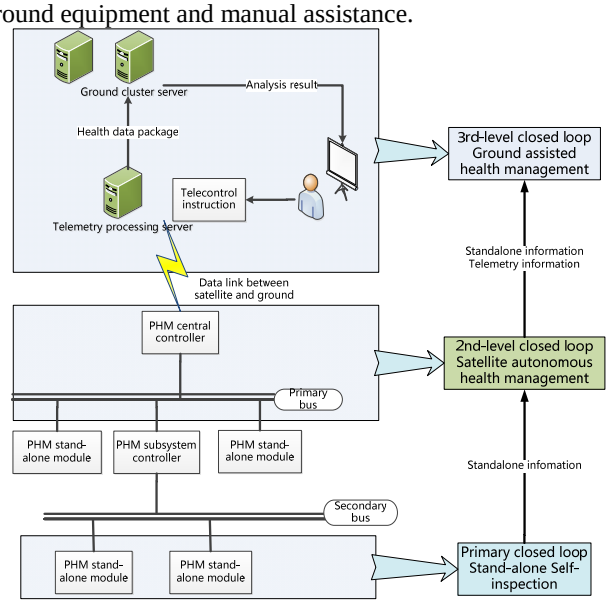

FIGURE I. ARCHITECTURE OF SATELLITE PHM SYSTEM

1) Satellite autonomous management system:

A master-slave mode is adopted, which is composed of a PHM master controller and several PHM modules.

Each PHM module is embedded in a single computer of each subsystem to complete the first level of closed-loop management, that is, single machine self-test. Each PHM module is embedded in each subsystem, which is responsible for health information collection, fault self-detection and information exchange with the host PHM controller.

The PHM master controller is responsible for the management of the whole satellite PHM system and completing the second-level closed-loop management of the satellite. It mainly has three functions. The first function is, the collection of health information from equipment, the issuance of self-test instructions and the integrated transmission of the whole satellite health information; the second function is that it is responsible for the system-level fault diagnosis and prediction. The system-level contains abundant information, which can synthesize the operation of the system to quickly diagnose and predict the fault of a single machine or subsystem. It is also responsible for the transit and transmission of satellite-to-ground PHM information, and extracting the information which cannot be judged independently by the satellite and needs ground support, then transmiting it to the ground through telemetry channels, returning the on-ground processing results and operational suggestions back to the corresponding satellite subsystem and stand-alone equipment. That's the third function of the PHM master controller.

2) Ground Auxiliary Support System:

This is the third level closed loop management of satellite and ground. The management unit is the ground server. The closed loop extends the time range of satellite fault diagnosis and prediction, enhances the capability of satellite health management by using the powerful computing and analyzing capabilities of the ground server to carry out medium and long-term complex fault prediction. The analysis report is generated and decision-making suggestions are given after the analyzing and processing, which provides basis for the on-orbit operation management personnel to suggest the management satellite status.

The design of PHM system with the feature of three-level closed-loop fully adapts to the technical characteristics of existing satellites. The single-layer PHM module can realize the high-speed sampling of single-machine health parameters. Each module can set sampling frequency according to the different characteristics of the single-machine to ensure that the fault features are not missed. The incoming health information can be selectively processed, or the data can be downloaded from the telemetry channel and handed over to the ground server for processing. The complex fault diagnosis and prediction work can be realized with less channel resources being occupied.

B. Design of PHM Internal Structure on Satellite

PHM on satellite adopts intelligent control design based on high-speed bus. It mainly includes three parts: system-level PHM controller, sub-system or single-machine PHM module and PHM bus. PHM module includes PHM data collection unit and PHM data processing unit.

As shown in Figure II, the PHM data acquisition unit can send commands to the sensor through the internal bus, control the sampling period, receive the acquisition results from the sensor, and then pack them into a separate data bus and send them to the telemetry subsystem and the upper PHM controller. The PHM data processing unit can also obtain the parameter data from the sensor and simply analyze the data to identify the typical faults, complete the self-test function, and transmit the detection information to the PHM controller and the remote control subsystem through the PHM bus and the remote control bus. The PHM controller is the top management unit of the whole PHM system. It receives, integrates and analyzes the information transmitted by the PHM module, to complete the whole satellite autonomous detection function, extract the corresponding information to transmit to the ground support system through the orbit-ground link, receive the ground auxiliary processing results and distribute them to each PHM module.

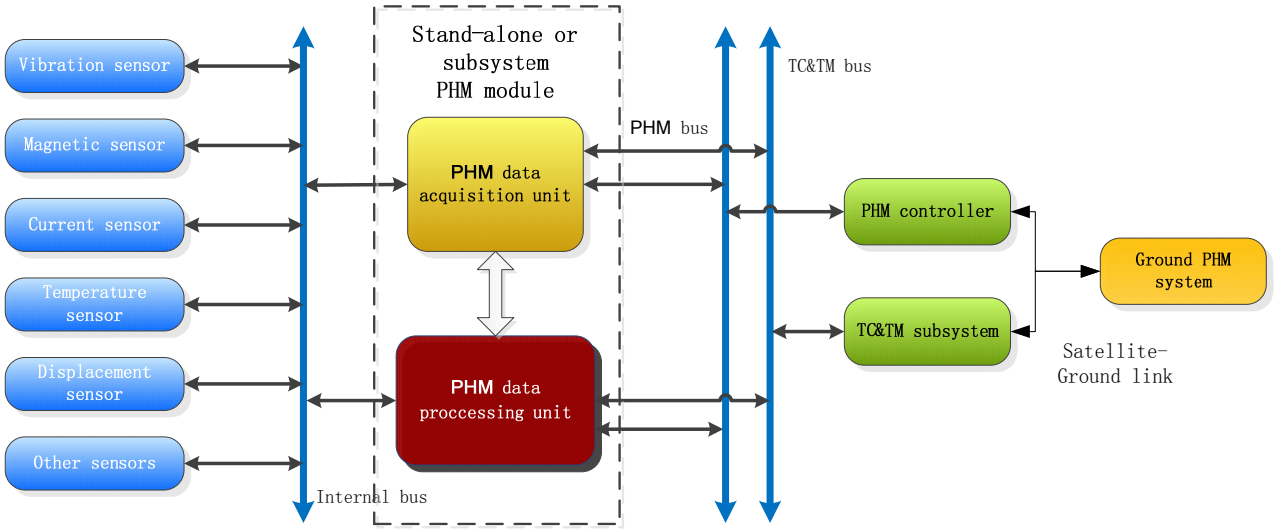

FIGURE II. ON BOARD PHM INTERNAL STRUCTURE

C. Design of PHM Communication Protocol on Satellite

PHM technology is a basic universal technology, and its application objects are all kinds of electrical equipment of satellite. The transmission requirements of health information are different among different devices because the kinds and quantities of health information in different devices are not the same. Therefore, the interaction and management of health information between devices has become an important research content in the design of satellite PHM system. The most important one is the design of PHM bus communication protocol.

Compared with the traditional satellite bus communication mode, PHM bus communication mode takes more consideration of the requirement of the whole satellite health management, and extensively refers to the system and standard accepted by each device design unit in the design of communication protocol. The onboard PHM bus has the following characteristics in the application of communication mode.

Adopting the idea of hierarchical structure, the transmission content is divided into several layers. Different layers have different functions and different data structures. The data units of each layer are equipped with a guide domain to record some useful information so as to extract the data of the target device conveniently and correctly at the receiving end.

Using multiplexing mechanism, i.e. packet channel multiplexing and user's dynamic channel sharing to improve the utilization of PHM bus data channel.

Set up different services to handle different kinds of data. Different types of stand-alone devices adopt different formats of data units, and finally merge into a data stream for transmission over physical channels.

Data link sublayer is the core of satellite-borne health data network. By defining a complete protocol mechanism, it can support the internal transmission and interaction of health data in data link subnetwork. "Virtual channel" is a very important concept in data link layer, which enables multiple high-level data streams with different service requirements to be able to share a physical space channel dynamically and on-demand. Each physical space channel is known as a virtual channel (VC), each VC has its own identity, providing a certain level of service.

The basic services provided by the PHM bus communication protocol include:

(1) Time Service

The time service supports sending the whole satellite time code at the bus control end periodically to the receiving RT end of each single computer through the bus. The service can be used for time synchronization within the health bus network. The sending process repeats the time code and time synchronization primitives step by step, and the two kinds of primitives can also be used separately.

(2) Communication synchronization service

The communication synchronization service supports time division multiplexing of bus messages and the certainty of message sequences, so that messages are determined before they are transmitted on the bus. The time period of data bus communication is called communication frame. Each communication frame on the data bus starts with a communication frame synchronization message, which is synchronized by a command with a data word indicating the transmission frame number. The service can be used for communication synchronization between PHM controller and single PHM module.

(3) Placement and fetch services

Placement and fetch services provide service users with the method of sending data of limited length from the source to the terminal via single service access. Any of these services allows point-to-point service users to communicate one-way, sending data from the source to the terminal in the original format. The service can be used to complete the transmission of health management commands, as well as the transmission of health status and data.

III. SUMMARY

This paper puts forward the design scheme of a three-level closed loop spacecraft PHM system for orbit-ground coordination, after analyzing and summarizing the research status of spacecraft PHM technology. It also analyzes the research system of PHM system technology for reference and discussion by relevant researchers, aiming to promote the application of PHM technology in spacecraft.

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