Present Situation, Challenge and Future of Health Management about Complex Equipment

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Abstract. Recently, the public has focused on the safety and reliability of complex equipment such as aerospace. Health management about complex equipment contains state detection, fault prognostics, fault diagnosis and so on, and is the guarantee for accomplishment of space missions and the long-term operation of in-orbit spacecraft. Under the background, the development of prognostics and health management (PHM) technology, aiming at improving equipment safety and reliability, which can eliminate faults in the embryonic state, has a profound significance for condition monitoring and in-orbit maintenance of aerospace equipment. By analyzing the research status and application of PHM technology both at home and abroad, the manuscript majorly addressed the PHM technical framework and key technologies about spacecraft. In the meanwhile, integrated with cloud service platform for equipment management, the development tendency of PHM was forecast. At last, the existing challenges of PHM technology was expounded and corresponding countermeasures were put forward.

1. Introduction
In the latest years, the whole world puts great emphasis on the space strategy, and gives impetus to the relevant strategy deployment. The aerospace launch activities remain highly active. According to the Blue Book of China Aerospace Science and Technology Activities(2019), which was released by China Aerospace Science and Technology Corporation(CASC), there were 102 implemented launch missions and 492 launched spacecraft in the world. While, China has accomplished 34 launch missions, ranking first of all the countries. The year of 2020 is the final year of the 13th Five-Year Plan, the critical year of 14th Five-Year Plan, and also the year of fully activating the construction of aerospace power. Weighty missions have been vigorously carried out, and have characteristics of heavy task and high emission density. Major missions like BeiDou Navigation Satellite System, Gaofen High-resolution Imaging Satellite are all about to be accomplished. In terms of manned spaceflight, space station mission needs to be prepared in advance. As to deep space exploration, Chang’e 5 mission and First Mars Exploration mission are to be executed this year. It is not difficult to tell that space missions are all related to each other and have no tolerance for any mistakes. For the satellites, spacecraft and space stations all cost much and are long-term unattended. Enhancing the reliability and maintainability of space equipment is of great significance to successfully accomplish space missions.

In summary, PHM technology is to process and fuse the data collected by multiple sensors, and does data analysis based on specific model and algorithm, so as to get the current situation and predict the tendency in the coming period of time, and make corresponding measures. Besides, PHM technology is being taken as the core technology of on-condition maintenance. As a solution to do fault diagnosis and health management, PHM technology shows up in the space equipment field simultaneously with information processing, sensor technology and prognostics technology. PHM
system applied into space equipment, generally adopts distributed structure, which is shown in figure 1[1].

![PHM structure of space equipment](image)

**Figure 1.** PHM structure of space equipment.

2. Current Situation Both at Home and Abroad

2.1. Current Situation Abroad

Mainly to minimize risks and losses in space missions, western countries, represented by the United States, have been devoted to research on the fault diagnosis technology of spacecraft since 1950s. PHM technology thrived from mid-1990s to the early 21st century. That PHM technology was used in the F-35 (JSF) fighter was the milestone in this period. Based on this project, US army initiated Autonomic Logistics Guarantee System.

2.2. Domestic Current Situation

By researching on the health management system of liquid rocket engine SSME, National University of Defense Technology made early fault detection[2] come true in the year of 1992, indicating the beginning of domestic researches on health management. Compared with the developed countries in Europe and the United States, domestic PHM technology starts later, and is mainly used in aircraft and spacecraft.

In the 21st century, domestic study on fault prognostics and health management technology has stepped into the fourth five-year plan. Researches on PHM technology gain emphasis from the national strategic level. Due to the lack of PHM technology reserves, the researches still remain in the simple application and verification of fault prognostics and health management for the key systems(for example, hydraulic, engine, integrated circuit ) of aircraft. So far, there is no complete PHM system suited for the aerospace equipment.

Generally speaking, domestic PHM technology has weak foundation and starts lately, and lags behind wester countries represented by the United States in the overall level.

3. PHM Technology Framework and Key Technologies of Complex Equipment

The key technologies of PHM mainly include testing technology, new sensor technology, fault prognostics technology and fault diagnosis technology. Common PHM technology framework can be described as follows. It is being used to monitor and collect the status data of equipment by testing technology, advanced sensor technology and other detection means, and to scientifically evaluate the health status of equipment based on key technologies such as fault prognostics (based on model,
knowledge, data prediction) technology and mine-fault diagnosis technology, so as to finally realize equipment health management. It is not hard to discover that PHM technology can be used to do “breakdown maintenance” and “periodic maintenance”, which is based on equipment status.

3.1. Testing Technology
Testing technology is the foundation for PHM system to do prognostics and health management. Testability design is needed to verify whether equipment meets the specified requirements. And reasonable testability design gives an expression of good testing technology. The workflow to do testability design is shown in Figure 2[3].

![Figure 2. Fusion scheme of equipment testability and PHM.](image)

3.2. New Sensor Technology
Recently, new sensor technology has developed rapidly in China. The most representative sensor in aerospace structural health monitoring field is FBG. It is mainly used to monitor a lot of test-waiting targets in stress field. The working principle is shown in Figure 3[4].

![Figure 3. Diagram of FBG sensor working principle.](image)

3.3. Fault Prognostics Technology
The ways to do fault prognostics can be roughly divided into three types, respectively based on the model, knowledge and data. Tailoring the most appropriate reasoning model and algorithm is of great help to locate the fault causes precisely and make effective maintenance strategies. The paper [5] concludes the functions, advantages and disadvantages of some fault prognostics methods, which is shown in figure 4[5].
4. Development Direction of PHM about Complex Equipment

4.1. Cloud Computing and Artificial Intelligence

"Cloud computing" was first proposed by Google CEO in 2006, making AI algorithm and high-speed computing ability of massive data possible. Normally, a typical cloud computing structure is divided into four basic layers, which is shown in Figure 5[6].

![Figure 5. Diagram of cloud computing structure.](image-url)

**Figure 4. Comparisons of fault prognostics methods.**
4.2. Cloud Service and Health Management Cloud Service Platform for Equipment

Cloud service is about web service deployed in the cloud computing environment. It can provide powerful calculation, data storage and resource sharing capabilities for PHM system. In paper [6], one equipment supporting company is taken as research subject, and a military equipment PHM platform framework based on cloud service(private cloud) is designed to better integrate equipment fault diagnosis resources. While in paper [7], a group enterprise is chosen as an example, and a fault diagnosis and health management service platform which is open, collaborative, on-demand, is constructed.

Health management cloud service platform for complex equipment can settle the bottleneck problems like shortage of PHM technology knowledge model, testability design and data. It also explores the new ways to do future develop of PHM technology, produces new penetration points of health management for complex equipment.

5. Challenges and Countermeasures of PHM Technology Development

5.1. Challenges of PHM Technology Development

By digging up recent domestic PHM technical reviews, it can tell that domestic PHM technology has a weak foundation, and has bottleneck problems of top design, technology and index verification, detection means, data accumulation, making it hard to meet PHM requirements of complex equipment, especially space equipment. The shortcomings appear as follows.

(1) Lack verification norms and technical manuals of health management for complex equipment. Through information, it can tell that there is little relevant PHM norms, no unified document norms, no verification norms and technical manuals to guide health management design for system, subsystem and single part. It is impossible to do reasonable and effective top design for PHM system.

(2) Lack PHM technology and index verification experience. The way to do fault diagnosis and prognostics varies in different systems and even in different parts of the same system. PHM technology and index verification both need to carry out massive supporting experiments. For the serious deficiency of domestic PHM technology verification investments, it is not easy to do valid verification of relevant technologies and indexes.

(3) Lack equipment situation detection means. There is no systematic study about “which parameters” need to be collected. People have no idea about “what to measure”. Testability of in-use equipment is relatively low, and they don’t know “how to measure”. Only with the existing equipment situation detection means, it is difficult to realize the functions of "thermometer" and "alarm".

(4) Researches on the data accumulation and failure model are insufficient. The accumulated effective experiment data of complex equipment is not enough. The failure model and mechanism studies on subsystems, system modules, parts are still vigorous. Though systematic PHM has been created, the foundation is not solid. In pursuit of advanced technology, the universality of technology is been ignored.

5.2. Countermeasures of PHM technology

In order to make progress, domestic PHM technology needs to start from the basics. Theoretical research, data accumulation need to make combination with the engineering practices. The following suggestions need to be taken to promote coordinated development of PHM technology and reinforce its universality.

5.2.1. Establish systematic self-initiated work.

PHM technology in China has shortcomings of late start, insufficient reservations, inadequate engineering experience, incomplete PHM system norms. It is urgent to draw lessons from worldwide PHM standards, combined with the actual domestic situation, to do independent innovations and built a series of PHM norms with Chinese characteristics and oriented to the new-generation equipment to strengthen top design.
5.2.2. **Strengthen technology integration verification of PHM.**

(1) Reinforce research and integration of advanced sensor technology, modeling technology, prognostics technology and fault diagnosis technology. (2) Make full use of new technologies such as cloud computing, artificial intelligence and cloud services. Exploit systematic and targeted PHM technology from single part to system level, and strive for a corner overtaking. (3) Strengthen processing PHM issues from the module level and part level, and pay attention to effective data accumulation and analysis. Enhance data mining analysis, and provide data support for the development of key technologies of PHM.

5.2.3. **Carry out scientific researches and supporting PHM technology researches in parallel.**

Researches on domestic PHM technology start late. Industrial departments and scientific research institutions both gain achievements, but they two are not synchronized, leading to PHM system not suitable for the complex system of space equipment. Hence, PHM technology research resources of all parties should be gathered speedily. To avoid repetitive research and resource waste, industrial departments and scientific research institutions working on the major projects should tackle jointly.

6. **References**

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