Prognostics and health management techniques for integrated avionics systems

Chenghao Li
Aviation Engineering Institute
Air Force Engineering University
Xi'an 7100038, China

Le Ru
Aviation Engineering Institute
Air Force Engineering University
Xi'an 7100038, China

***Abstract*—Avionics system is an important part in the development of China's aviation industry. With the continuous improvement of China's science and technology and productivity level, China's aviation industry has made great achievements, which is due to the rapid development of avionics system technology. However, most of the aviation accidents are caused by the failure of the avionics system, which has caused great losses to the country and people. Therefore, the research on prognostics and health management technology of avionics system is to ensure the performance and safety of avionics system, and is an important guarantee for the rapid and stable development of China's aviation industry. In recent years, the prognostics and health management system (PHM) based on condition maintenance has overturned the traditional timing maintenance technology. It can not only make advanced prognostics in advance, but also carry out health management for the system based on the result of prognostics. This paper analyzes and studies the fault prediction and health management technology of avionics system, and analyzes the application and future development trend of PHM in integrated avionics system, so as to ensure the safety of aerospace industry.**

Keywords: prognostics and health management (PHM); avionics system; on condition maintenance

I. INTRODUCTION

In the aviation equipment and aviation system fault, the fault caused by the electronic system has reached more than 40% of the total fault factor proportion. at the same time for the maintenance of electronic equipment and electronic system accounts for the total consumption of one third. According to statistics, in the whole life cycle of an aircraft, the failure of the avionics system accounts for more than 40% of the total failure of the aircraft system, and the use and support costs account for more than 70% of the total cost [1]. Therefore, avionics system prognostics and health management is important. With the development of high technology in the global field, the avionics system is changing. While its function and performance are more powerful and superior It also brings technical difficulties to the failure prediction of avionics.

From the current technological analysis, the traditional BIT and timing maintenance, this detection method has great limitations. With the rapid development of computer technology, a new concept of prognostics method appears. compared to the previous technology, prognostics and health management as a new technology plays an important role for the improvement of stability and integrity of the avionics system, the success of the task, the increasing efficiency of the security and the decreasing security cost. And it can also realize the high speed development of aviation industry in China. There is an urgent need for PHM technology both at home and abroad. n recent years, the development of PHM technology enables the integrated avionics system to achieve complete monitoring of the whole system and complete real-time detection of some key components. At the same time, for the data level, it can timely report and display all kinds of data of avionics equipment, which lays a good foundation for the fault detection and health management of the whole avionics system

The paper [26] comprehensively analyzes the application scheme of the system from the aspects of system architecture, sensor network, fault prediction and decision guarantee, providing reference for the construction of electricity information acquisition system. The paper [27] analyzes the application and future technology development trend of PHM electronic system in the field of aviation assembly through the elaboration of PHM electronic system structure and function, so as to escort the safety of aerospace industry. The paper provides a reference for PHM technology development based on PHM key technology, theoretical research status and future development trend applied in integrated avionics system.

II. OVERVIEW OF PROGNOSTICS AND HEALTH MANAGEMENT TECHNIQUES (PHM)

As the name suggests, prognostics and health management technology can be divided into two parts: fault prediction and health management. For avionics system, prognostics is to effectively predict and monitor the performance and state of each unit or module of avionics sensor system, so as to predict the service life and fault type of each component of avionics system. According to the prognostics information, health management judges and manages the function and status of the

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avionics subsystem, so as to make appropriate decisions on maintenance resources, requirements and later activities [2].

Compared with the traditional fault prediction method, PHM technology can comprehensively predict the entire avionics system and realize more intelligent prediction and supervision by using the intelligent diagnosis system. It can not only greatly reduce the occurrence of fault recurrence and manpower input, but also reduce the scale of logistics support, decrease maintenance costs, and extend the service life of the aircraft. At the same time, it makes a greater contribution on improving the equipment readiness rate.

III. Application and research status of PHM technology inside and outside China

In the 1970s, the extensive application of complex systems brought rapid development to many fields, but the subsequent increase of system failure rate has brought problems to many systems, which prompts people to have a further study on the functional state of the system. By means of fault protection of equipment and system stability improvement, the study on accident prediction promotes the development of prognostics technology.

With the increase of equipment maintenance and logistics support, the problem of equipment maintenance becomes the main factor restricting the equipment development and the efficiency of task completion. The emergence of the concept of "health management" has a very good value for controlling and reducing equipment maintenance resources, so as to improve the maintenance support task from the past results-based maintenance to the process-based active and targeted maintenance

A. Applications outside China

In the field of military applications, the U.S. military has launched a large number of related projects and applied research, such as the integrated system health management of the U.S. air force laboratory, the integrated state assessment system of the navy, and the army diagnostic improvement program of the army [3]. In the field of military aviation, the earliest and the most widely application is in the army helicopter using the health and use of monitoring and control system, HUMS are widely used in the UK, USA, Canada, the Netherlands, Singapore, and Israel and other countries on the equipment of the helicopter. The army has approved in all of the AH-64 helicopter gunships is installed on the system. According to statistics, HUMS can increase the completion rate of helicopter missions by 10%. In 2002, the U.S. Department of Defense put forward the concept of CBM plus, which is used for overall planning and design of state monitoring, life prediction, maintenance decision-making, logistics support, cost control and so on, to further improve the health management ability of equipment systems. In 2006, Teradyne developed the aircraft health management system AHMS aiming at the U.S. navy's P-8A multi-mission aircraft. In addition, the PHM system has been successfully applied to the F-35 jointly developed by the United States and other countries [4]. In 2011, the UK equipped HUMS for future Lynx helicopters, which can monitor the flight and use status of the helicopter and record the voice and flight data in the cabin. In addition, the system will be equipped to the army battlefield reconnaissance helicopter and the navy marine rotorcraft [4].

After continuous promotion, PHM technology has also been widely used in the civil field, among which the Aircraft Health Management (AHM) system developed by the Boeing Company is the most famous. By using this system, the flight safety and flight operation efficiency of multi-type civil airliners of the United States, France and Japan have been improved. According to the Boeing Company, airlines have reduced their costs for delays and cancellations by about 25 percent by using the AHM system. AHM system can also identify repeated failures and predict the development trend of avionics system, so as to support airlines to achieve long-term reliable operation [5]. Meanwhile the NASA is the authoritative research institution in the field of civil application of PHM. It began to carry out research on the application of health management in rocket propulsion in the 1980s. In order to reduce and control aircraft failures, the aircraft integrated health management system was designed for reusable space launch vehicle X-34. In the 21st century, the NASA John H. Glenn Research Center, the Jet Propulsion Laboratory and other research institutions to carry out integrated system health management research, which make the application of PHM extend from large aircraft, the Mars Exploration Rover and other aerospace fields to nuclear power facilities, automobiles and other more extensive fields [6].

B. Applications inside China

Compared with western developed countries, domestic PHM technology started late and is still in the primary stage. It mainly studies the system structure, principle and application of specific objects, but there is no complete engineering practice of system application, which is far from developed countries. The PHM performance requirements, quantitative evaluation and verification methods are analyzed according to the uncertainty characteristics of PHM technology in literature [7]. The health characterization parameters of radio frequency channels of airborne avionics systems are studied in literature [8]. The framework of integrated avionics PHM system is designed, and the supporting technology of subsystem PHM is analyzed from predictability design, fault prediction technology and health management technology in literature [9]. The solution to realize inertial navigation system health management is provided according to the performance pipeline system health management architecture in literature [10]. The application of PHM technology in radar equipment is studied in literature [11,12]. The software platform design of the expert system of avionics system health management is studied in literature [13]. The advantages and application status of current PHM technology is analyzed, and the wired wireless data transmission technology is discussed in literature [14]. According to the technical characteristics and maintenance support requirements of the new generation combat aircraft, the hierarchical PHM system architecture is proposed, which is integrated four layers, namely module/unit layer, subsystem layer, regional PHM and platform PHM in literature [15].

C. Theoretical research status

With PHM technology advancing well and significantly in every field, the U.S. military has developed a comprehensive, industry-leading forecasting and health management system for

the F-35 [16]. At present, researches on PHM technology of avionics are mainly carried out from the following aspects:

1) Stress damage assessment: External environmental stress will damage electronic devices and reduce their reliability, which is an important cause of electronic equipment failure [17].

2) Failure mechanism: After electronic devices are manufactured, their performance will gradually deteriorate. Since VLSI is the core component of all avionics, its failure mechanism is the focus of reliability technicians [17]. Therefore, it is necessary to embed several sensors in the product to sense the external load (temperature, temperature change, humidity, vibration, impact, pressure, voltage, current, etc.) [18].

3) Fault symptom: The circuit characteristics of electronic products gradually age with the increase of service time. In the device, circuits and systems, therefore, the failure mode and the harm endanger analysis (FMEA), on the basis of selecting appropriate physical quantity related to the failure, such as frequency response, magnification, matching the impedance as fault signs or indications, failure prediction model is established, by monitoring the circuit parameters selected, can evaluate the performance of electronic devices and electronic devices, predict fault components and equipment.

4) Fault warning: The circuit board can bear more stress by setting fault warning circuit on the circuit board module, and its failure process can be accelerated compared with other circuits on the circuit module, so as to predict the failure time of the circuit board [19].

IV. KEY TECHNOLOGY ANALYSIS OF AVIONICS PHM SYSTEM

A. Data acquisition and multi-sensor fusion technology

When PHM is applied to complex system objects, the parameters directly representing the health state need to be confirmed first. In addition, it is also necessary to actively collect some parameters that can indirectly infer the health status of the PHM system. All this information is the basis of the PHM system operation process, which must be reinforced in terms of accuracy. In the process of obtaining such information, it mainly includes the type of sensor, the accuracy of the sensor, the bandwidth, the position of the sensor and the monitoring parameters. Because electronic systems have a wide variety of faults, PHM systems usually require further monitoring of parameters such as heat loss of voltage and power, temperature, humidity, shock vibration and so on. In practice, accuracy cannot be guaranteed, so PHM technology also needs to pay attention to the diversification and miniaturization of sensors. In addition, some other parameters need to be monitored, such as electrostatic damage time and breakdown of related media. However, these parameter sensitive sensors are rare, so further development must be carried out [20].

Multi-sensor fusion technology refers that composed of several sensors with coordinated, complementary and competitive nature of the sensor array, under a certain criterion for auto/intelligence analysis, processing and comprehensive, get more accurate and fully than a single source of information to complete the required decision-making and evaluation of the multi-level various information processing, which obtain accurate status and trend of the estimate.

B. Fault diagnosis technology

Prognostics technology refers to the use of sensors to detect system state characteristic parameters. Combined with other data information, the current health status of the system is evaluated to achieve the purpose of diagnosis and monitoring. Prognostics technology can be divided into three methods: analytic model-based method, signal process-based method and knowledge-based method. The analytic model-based method is to process and diagnose the tested information according to certain mathematical method on the basis of knowing the mathematical model of the diagnosed object. The signal process-based method is to use the signal model to analyze the measurable signal directly and then detect the fault. On the basis of knowledge processing technology, knowledge-based method realizes the integration of dialectic and mathematical logic, the combination of numerical processing and symbolic processing, the combination of algorithm process and reasoning process, and achieves the purpose of fault diagnosis through knowledge-based concepts and processing methods.

C. Prognostic technology

Prognostics technology is in the understanding of the equipment under the condition of data and change trend, when there is minor defect in the system, subsystem or component part to predict different time after the equipment state parameter, finally diagnosed predict the parameters of the state, and then to the current state of health to make accurate speculation ,which is based on the state parameter, working conditions, usage ,environment and the help of some prediction models of computation. The fault prediction of avionics is very complicated, so different methods should be chosen according to the actual equipment situation.

1) Prognostics based on working status: The fault prediction of avionics can be realized by some basic working state data of avionics. For example, the VLSI circuit, an important component in avionics, will significantly increase its static current when the device is aging or the local circuit within the device is damaged. In this case, the device will soon be damaged due to excessive heating during operation. Therefore, VLSI circuit static current changes can be used to predict the failure of devices and equipment

2) Prognostics based on data: Using this system work history data as the main means of fault prediction system, implementation approach is to adopt the corresponding intelligent algorithm to measure, extract system fault and train failure characteristic of expanding over time, and then it can get the corresponding intelligent prediction model structure, and identify and sign corresponding features under similar conditions of system state. The typical algorithms are neural networks and support vector machines.

3) Prognostics based on performance parameters: The performance parameters of avionics can reflect the health condition. GPS receivers used in JSF of the U.S. army can use their positioning errors as parameters to predict the accuracy faults of GPS receivers, and their receiver discontinuity

frequency as parameters to predict the receiver reception faults[21]. This method is suitable for avionics equipment with continuous variation range of main performance indexes. Prognostics based on parameter prediction is usually necessary to establish the quantitative relationship between parameter variation and failure through accelerated failure test on the basis of the rating and tolerance given by product performance indexes for fault prediction.

D. Health status classification

Health status classification is an important part of PHM technology. Its purpose is to determine the current health state of the equipment, and then to evaluate the deviation degree of the traveling state. However, the premise of health status assessment is that the health status of the equipment is polymorphic, and it cannot only be "normal" and "failure". For avionics system, the state of avionics equipment can be defined as the following five states. The normal state is that the equipment operates in a predetermined manner, and all predetermined functions are completed according to the specified performance indexes. The error state is the accidental, non-stationary, and non-scheduled state of the re-running of the device or program, and the detection performance is not fault observed. The failure state is a state in which a product is unable to perform specified functions. The abnormal state refers to the state when the device deviates from the predetermined operation mode or specified functional range, which is manifested as functional degradation. The damaged state is the state in the equipment where the failed parts are not recoverable and cannot perform the specified functions.

The methods of health state classification include qualitative classification and quantitative classification. There are two methods for the quantitative division. One is to establish a certain health state function (curve) for the division [22]; The other is by determining the state boundary (threshold) between each state to carry on the division [23]. According to the requirements based on knowledge and experience or clustering model, qualitative classification method mainly USES the data of performance parameters and divides the health state of objects into several categories, which includes two categories that expert scoring, AHP method [24] and other methods using knowledge and experience, data mining and intelligent algorithm [25].

V. SUMMARY AND PROSPECT

Avionics system is becoming more and more important in modern aircraft. Modern aircraft have adopted telex operation. Therefore, the function of avionics system has a direct relationship with the flight safety of aircraft. Therefore, the health of avionics system is closely related to the flight mission.

The essence of PHM technology is to carry out Highly Informationized state monitoring of aircraft and to manage aircraft with high timeliness and precision. PHM technology has become an important technology in the field of aviation all over the world [23]. Due to the increasing complexity of the electronic system, the current diagnostic technology is more capable of timely fault detection and troubleshooting than the traditional fault diagnosis technology. Compared with the regular maintenance, it has higher efficiency, which can not only reduce the scale of logistics support, but also avoid the occurrence of safety accidents. However, at the present stage, PHM technology has some problems in application, such as small diagnosis range, low fault detection rate and high false alarm rate. Therefore, more and more in-depth development work should be done on how to apply PHM technology from the proposal to the actual application.

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