Application of prognostic and health management in avionics system

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Abstract. Currently, most aircraft avionics systems are maintained based on reported failures or periodic system replacement. However, the evolution of prognostic and health management (PHM) concepts from mechanical to electronic systems and further to avionics system maintenance has been driven by changes in weapon platform procurement and support requirements. At the same time, with the increasing complexity of avionics design, integrated modular avionics (IMA) came into being. The appearance of IMA design concept marks the gradual transition of avionics system from distributed joint architecture to integrated architecture, which also provides the foundation for PHM technology to be applied to avionics system. This paper reviews the application and research status of predictive and health management system technology in avionics system.

Keywords: Prognostic and health management, Aircraft avionics systems, Health management.

1. Introduction

Avionics system refers to a collection of all airborne electronic equipment, including control system, state perception system, human-computer interaction system, navigation system, task execution system, background management system, communication system, such as integrated electronic system, also including responsible for collaborative information interaction system between subsystems and task management system [1]. The appearance of avionics system greatly improves the performance of aircraft, reduces the burden of pilots, and provides abundant information and decision support for pilots [2]. With the rapid development of civil and military aircraft, people's demand for Avionics system is more and more complex, Integrated Modular Avionics (IMA) arises at the historic moment [3].

In the early days of health management, unplanned maintenance was used to maintain the system, that is, when the system failed, the maintenance was checked. In order to reduce the number of failures, scheduled maintenance is adopted in critical systems, that is, regular plans are made to check the use of the system and replace the components in the state of attenuation [4]. Planned maintenance reduces the failure rate to a certain extent, but also increases labor cost and maintenance cost. With the increasing risk and cost of failure, traditional planned maintenance can no longer meet the requirements of aircraft availability [5].

To date, the PHM concept has been widely applied to mechanical systems such as engines, drivelines and pumps [6]. A variety of prediction methods have been developed for such mechanical systems, including empirical trends, damage accumulation, fail-to-failure progression, and physical failure models. Safety, reliability, testability, maintainability and supportability are all critical to modern aircraft. Prognosis and health management (PHM) is an essential capability to improve aircraft performance above. In recent years, the development of PHM technology has been widely concerned by the military industry and industrial circles of various countries, and PHM technology has been actively developed and applied [7].

2. Prognostics and Health Management Applications in Aviation

2.1 Aeronautical PHM system framework

2.1.1 Basic Implementation Framework [8].

The research framework of aviation PHM system based on PHM big data center is shown in Figure 1, which describes the basic implementation framework of the system and shows the functional requirements of the aviation PHM system. PHM center mainly collects all kinds of information of aviation component members, such as aircraft, airport, spare parts warehouse, repair shop, maintenance training, overhaul base, accident rescue, etc., and establishes a huge aviation database. Then, based on cloud computing server, data mining is carried out to obtain various failure experience and knowledge required by PHM. Can provide decision support to aviation participants, government or industry. Finally, PHM functions of independent monitoring, health management and emergency response can be realized through efficient linkage of aviation participants [8].

PHM center obtains flight data from aircraft, aviation operation data from airport, spare parts supply information from spare parts warehouse, maintenance information and experience from repair shop, maintenance training point and overhaul base, and receives accident handling tracking information from accident rescue site. Then, PHM center conducts comprehensive analysis on the information, mines the correlation of data, and obtains the statistical rule of failure rate and experience related to the failure. According to the analysis of the results, the center of PHM can offer aircraft condition monitoring and fault prediction of technical support, provide aircraft health status and operation of the airport, provide configuration recommendations for spare parts warehouse, to provide technical support for the fault maintenance factories and overhaul base of diagnosis and maintenance, maintenance and training of personnel training advice, accident rescue accident emergency response Solution. [9]

PHM Center provides aviation practitioners with comprehensive services based on big data mining to realize efficient utilization of information and improve the operational efficiency of aviation industry chain. For example, the airport can directly obtain the health status of the aircraft, and allocate the flight tasks of the aircraft reasonably, so as to improve the utilization rate of the aircraft. It can make reasonable maintenance or overhaul choices according to the health of the aircraft, and also enable the spare parts warehouse to prepare materials before the arrival of the aircraft, thus shortening the maintenance cycle and returning the safe and usable aircraft to the airport in time.

2.1.2 Engineering Proposal [8].

The engineering applications of aviation PHM mainly focus on independent monitoring, health management and emergency response. As shown in Figure 2, different engineering applications correspond to different key technologies, scientific problems and engineering application systems.

Independent monitoring.

It mainly solves the independent monitoring problem of various aviation data, and has certain fault detection function, but it does not necessarily have fault diagnosis and fault prediction ability, which is a broad category of PHM. The aviation safety independent monitoring system is a set of real-time safety monitoring system developed by third party. It can monitor the flight location, posture and state of the aircraft independently in real time, not in the safe monitoring method of the flying mechanism.

Key technologies include: airborne equipment data collection and storage, flight data rapid interpretation, and ground space data transmission. Scientific problems include: unable to adapt to real-time interpretation, unable to realize the direct and rapid interpretation of the logarithmic flow, and a real-time state monitoring method based on intelligent reasoning is proposed. The application system requires the development package: the aviation safety independent monitoring system: the software system that does not affect the normal operation of the airborne system, realizes the software system of data collection, storage and automatic interpretation, and sends important fault information or flight data to the PHM center through the ground space data link.

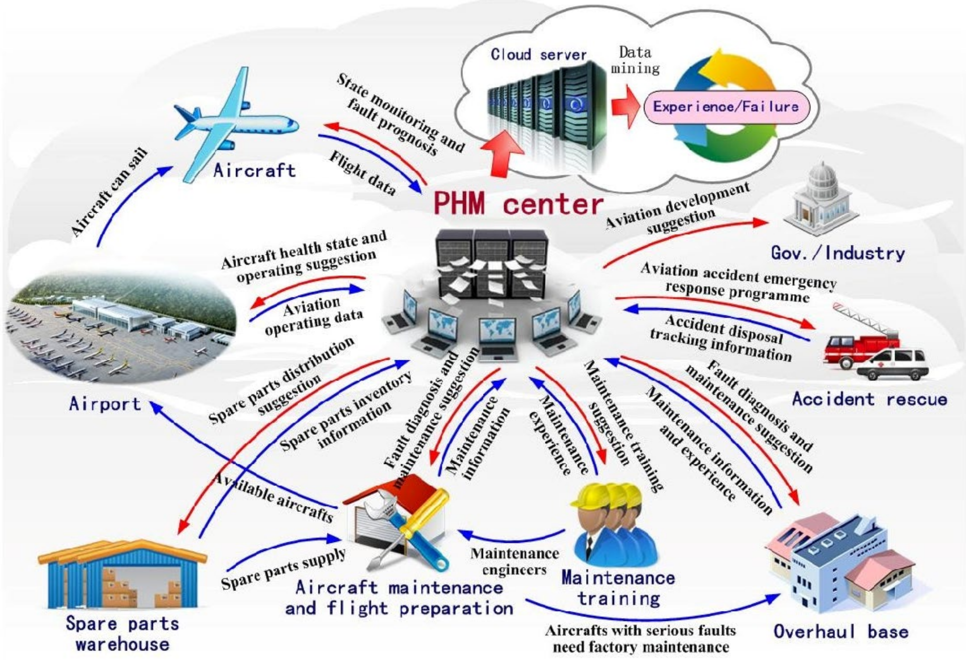

Figure 1. Research framework of aviation PHM system based on PHM big data center [8].

Health management.

It mainly solves the health management problems of the whole life cycle of aircraft, such as health status assessment, fault diagnosis, fault prediction, etc., which belongs to the narrow PHM category. It includes two parts: health management of individual aircraft and health management of aircraft cluster. The first part mainly uses the methods of reliability analysis, fault diagnosis and fault prediction, and integrates aviation big data to achieve aircraft health management. The second part is based on the health management of single aircraft, through the management and mission planning of available aircraft, cruise aircraft, aircraft in need of repair and aircraft in repair, to achieve the efficient use of aircraft cluster.

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Emergency response.

It mainly solves the emergency response problem after the abnormal or failure of aircraft, which belongs to the broad scope of PHM. Based on aviation big data, it adopts various data mining techniques and models to achieve comprehensive management of aviation maintenance, spare parts inventory and emergency disposal. It can timely implement the linkage of aviation related units to achieve the goal of aviation safety emergency response.

Key technologies include: aircraft maintenance decision, spare parts inventory optimization allocation, accident emergency treatment. Scientific issues include: cost-effectiveness-based planning and management. Application system needs to be developed including: spare parts warehouse material management system, aircraft state maintenance management system, aviation accident disposal and tracking management system.

Among them, the key technology is the important support of aviation PHM technology. Scientific problems extracted from key technologies must be given due attention in theoretical research. The application system is the final product developed based on these key technologies. These are all important components of achieving the objectives of aerial PHM.

2.2 PHM framework for avionics system

The research framework of avionics PHM is shown in Figure 2. The main contents of avionics PHM design include PHM overall design, PHM system central management design and PHM hierarchical structure design [10].

The central management design includes: determining health baselines, fault diagnosis and predictive logic; Design PHM system data structure; Design the function and content of PHM system software.

The design of PHM hierarchical structure includes: designing fault detection, isolation and prediction ability of each part of PHM hierarchical structure; Design the communication protocol and standard of PHM indirect interface; Design PHM hierarchical structure of each part of the test content methods and procedures; Determine the selection layout and optimization of the underlying sensor.

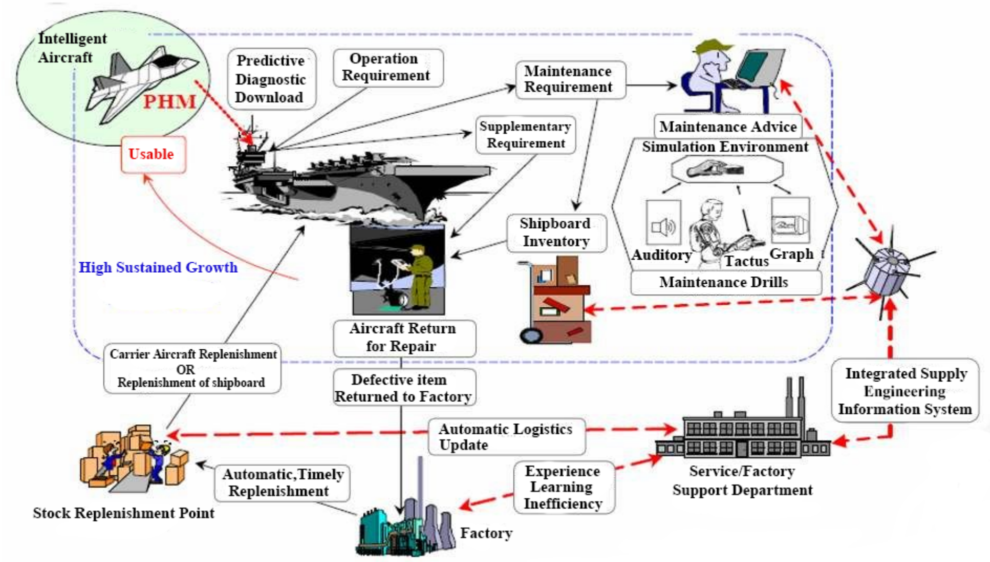

Figure 2. Autonomous logistics support system flow based on PHM.

In order to facilitate integration and modular design, the PHM system of avionics adopts a hierarchical design, which is divided into three layers: member system hardware and software monitoring program, area manager and aircraft platform manager. Due to the different functions and characteristics of these three layers, it is necessary to design these three layers respectively.

2.2.1 Member system hardware and software monitoring program.

The hardware and software monitoring of the member system mainly completes the acquisition and processing of the underlying state data of the PHM system, which is mainly composed of sensors distributed in each part of the avionics and self-testing BIT (Built in Test). BIT can be divided into analogy signal-based BIT and digital signal-based BIT by circuit. The output results of each member system BIT are transmitted to the region manager through the interface for processing.

BIT based on analogy signal.

There are many analog circuits in avionics products, and there are many analog signals, such as position and attitude signals of navigation output, altitude signals of altimeter, radar scanning signals and so on. BIT based on analog signals is to take a comprehensive approach to processing these signals. In order to fully obtain the state data of the system, ensure the coverage and reliability of BIT, and provide enough input for the next layer, BIT design based on analog signal should include circuit output value, power state, clock state, pin interconnect state (open and short circuit, etc.) [11] [12].

BIT based on digital signal.

In avionics system control and processing circuit, contains a lot of CPU, DSP and other large-scale integrated circuit, the circuit and the circuit of data exchange between adopt digital signal, state information avionics products without these digital signals, based on digital signal BIT is used to monitor the circuit of data flow. The BIT of digital signal can be divided into two methods. The first is the independent detection design in the digital circuit. At present, many chips have self-detection function, and active testing software can be embedded in the chip to test the chip itself. The second is BIT design at the whole machine level. The autonomous detection capability of general chips is limited and cannot complete all functional tests, such as continuous detection of communication status. This requires multiple circuits to do the detection together, improve the detection accuracy, reduce the false alarm rate, and finally give the circuit is normal or not [13].

2.2.2 Region manager design.

The PHM region manager of avionics system is a real-time executor for continuously monitoring the running status of the corresponding subsystem of the aircraft, which performs the functions of state signal processing, information fusion and regional inference machine. It includes three parts: state signal gathering, health information reasoning and state arrangement and output, as shown in the Figure 3.

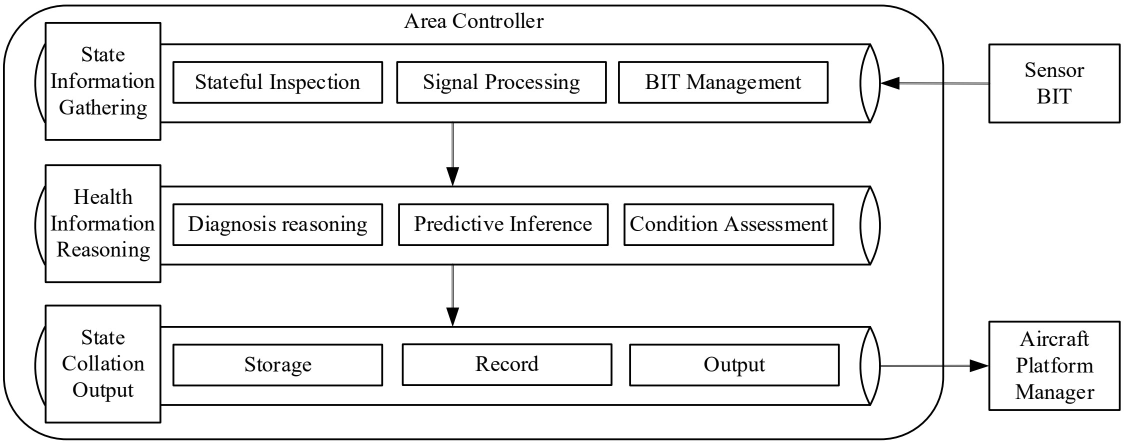

Figure 3. Autonomous logistics support system flow based on PHM [14]

State signal gathering.

According to the signal data type, the member system hardware and software monitoring program can transmit information to PHM area management in two ways. Analog signals through the signal interface, digital signals through the transmission bus.

Reasoning with health information.

Health information reasoning mainly carries out fault diagnosis reasoning, prediction reasoning and state evaluation at regional level according to the collected state signals. In the process of reasoning, not only the state data of each subsystem is considered, but also the inference is carried out according to the cross-correlation structure between subsystems.

State collation and output.

State reorganization and output is to record and store the reasoning results of health information, and finally output to the aircraft platform manager. The health reasoning results at the region level and the historical data of each subsystem are stored in a specified data structure in the region manager and transferred to the next layer through the interface.

2.2.3 Aircraft platform manager design.

The aircraft platform manager resides in ICP (Integrated Core Processor), determines, monitors and isolates faults according to the interconnections between regions through various status and fault information provided by the regional manager, and reports health status and maintenance information. The reasoning machines in aircraft platform manager are divided into predictive reasoning machines, diagnostic reasoning machines and abnormal reasoning machines. The predictive inference machine relies on all the predictive inputs from the subsystem to predict the remaining life of the subsystem components. The diagnostic inference machine records various diagnostic inputs from the subsystem to determine the cause of the failure. The abnormal inference machine classifies abnormal behaviors and collects non-rated data, which can be used to update the diagnostic and predictive inference machine.

3. Research Actuality

In the early days of health management, unplanned maintenance was used to maintain the system, that is, when the system failed, the maintenance was checked. In order to reduce the number of failures, scheduled maintenance is adopted in critical systems, that is, regular plans are made to check the use of the system and replace the components in the state of attenuation. Planned maintenance reduces the failure rate to a certain extent, but also increases labour costs and maintenance costs. With the increasingly high risk and cost of failure, traditional planned maintenance can no longer meet the requirements of aircraft availability.

There is no doubt that the Health Management System (HM) is one of the most important modules to ensure the availability of the entire IMA system. Once there is a risk, if it is not handled properly and in a timely manner, it will lead to different levels of consumption. However, as the complexity of the system increases dramatically, the deterioration of the system becomes harder to identify. If unknown faults occur and are misdiagnosed by HM, the whole system may be in danger or even fail, resulting in considerable losses [15].

With the development of IMA, based on the task of IMA in aircraft is more and more important, especially aircraft flying and combat mission, IMA after the possibility of failure and the failure to pay the cost of the price is becoming more and more high, urgent need to develop to analyse index data and estimate the potential risk in advance of the system, to protect the IMA The Prognostics and Health Management (PHM) system was developed due to the high availability of systems and aircraft. Compared with HM, PHM pays more attention to the situation maintenance and prognostic maintenance, that is, through advanced health prediction and detection methods and tools, it can predict the system state in advance and predict the hidden risks of the system, so as to avoid the failure risk.

PHM plays a crucial role in IMA, which is mainly reflected in the reduction of repair and maintenance costs, the improvement of system execution efficiency, and the reduction of downtime. For example, statistics show that after the introduction of PHM-related technologies, the failure rate of F-35 aircraft was eliminated by 70%, downtime was reduced by 40%, and maintenance costs were reduced by 30% [16]. At the same time, the development of avionics PHM technology can also promote the related research of other industries forward, realize the synergistic development and joint promotion between industries, promote the increase of economic benefits at the social level, and improve the utilization rate of resources.

Airborne PHM system and its related technologies have evolved from external testing to in-machine testing and then to in-smartphone testing in the early stage, gradually forming an independent testing discipline. With the development of the discipline and the integration of cross-disciplines, a comprehensive diagnostic test was put forward, and then developed to the present PHM technology of both prediction and diagnosis [17].

In the 1960s, aircraft systems were in their early stages of development. At that time, the aircraft architecture was relatively simple, and the avionics system was a separate structure, so the inspection of the aircraft system mainly depended on external tests. The working method is to independently inspect the components of the aircraft system on the ground and isolate the problems existing in the system. The U.S. Army used this health management model in its early equipment helicopters. Early aircraft system research and development requirements directly promoted the emergence of reliability theory, system test methods and other methodologies. With the increase of aircraft system complexity, in-flight testing is introduced into the system. The main function of built-in Test (BIT) is to provide necessary fault warning for pilots and assist maintenance engineers to troubleshoot faults. In the 1980s, in order to further improve the efficiency of BIT and solve the defects of traditional BIT, the former Roma Aviation Development Center in the United States proposed intelligent BIT In the practice. The core idea of intelligent BIT is to synthesize environmental data, historical data and sensor data by means of artificial intelligence, so as to reduce false alarm rate and improve diagnostic accuracy. After several generations of evolution, intelligent BIT has formed BIT technologies including maintenance history, decision improvement and adaptive testing. Smart Bits can be found in third - and fourth-generation aircraft, such as the F-22 and JSF [18].

Since the BIT device's diagnosis is carried out inside the system device, the faults of each system are isolated and diagnosed independently, lacking a comprehensive process. With the further increase of aircraft system complexity, the health testing method based on BIT has exposed some problems, such as high false alarm rate, low diagnosis efficiency, long diagnosis time and so on. In 1983, the United States original Safety Industry Association proposed the idea of integrated diagnosis, emphasizing that diagnostic sources and results among various elements of the system should be investigated comprehensively. This idea promoted the development of aircraft system health testing methods, and was recognized and advocated by the United States military.

In the 1960s, reliability theory and environmental testing theory were born, which brought theoretical development to system health testing. In the 1970s, the aerospace field proposed "integrated health management" to achieve comprehensive condition monitoring and analysis. At the end of the 20th century, the LAUNCH of the F-35 Joint Strike Aircraft project marked the birth of PHM technology. In THE JSF project, the comprehensive solution for fault prediction and maintenance is named PHM, with which the JSF project can be made available, reliable and sustainable [19]. Since then, PHM has been widely used in various aviation systems, including the new generation health and condition monitoring system of the US Department of Defense, the Integrated condition Assessment System used by the US Navy, the Diagnostic Improvement Program used by the US Army, and the Integrated Health Management System of aircraft used by NASA.

In the 1970s, with the development of the aircraft system, China's aviation equipment health inspection adopts the experience to determine the inspection content and time, and then judge the maintenance method. In 1979, China's Air Force proposed certain three changes, the technical standards are re-formulated, the maintenance of the means involved, procedures, system reform, this move to promote the maintenance of the efficiency of the project significantly improved, to J-6 as an example, its inspection hours shortened by 50%. In the 1980s, with the development of a large number of comprehensive diagnosis technologies such as signal processing and fuzzy reasoning, China's HM system also has a rapid development, in the J-10 aircraft used in the power, flight control, power supply and other systems are the development of fault detection and diagnosis system. The research and application of PHM in China lags behind the advanced level and is still in the initial stage. As an important system to ensure the reliability of aircraft, PHM must be considered in the development of new aircraft. Over the past few decades, PHM technologies such as data processing, feature extraction, fault diagnosis and fault prediction have become increasingly sophisticated. New PHM algorithms and technologies are emerging. However, there is still little research on PHM system architecture. With the rapid increase in the complexity of PHM systems, modular and flexible system architecture is needed to integrate PHM components and guide the development of PHM systems through standardized design standards. In decades of practice abroad, standard protocols closely related to the construction of PHM system architecture have been formed, including: Recommended procedures for description of software intensive system architecture, guidelines for design and application of in-machine test system, guidelines for design of airborne maintenance system, standards for machine condition monitoring and diagnosis, standards for open situational maintenance architecture, etc. These standards describe a series of basic steps and general methods to be followed in the top-level design of PHM systems. Due to confidentiality considerations, these standards remain at the top-level design level, and there are still many practical challenges. In the research on PHM architecture at home and abroad, it is found that most of the research on PHM architecture is carried out according to the traditional process of PHM system design centering on a specific system. However, due to the late start in China, the gap between top-level design and concrete system design still needs to be filled in the simulation and verification of PHM architecture. Only based on the architecture simulation platform with high flexibility and fast construction speed, can the PHM system development for various specific systems be completed efficiently [18].

At present, the overall framework design of aerial PHM is concerned. Other related research includes theories and methods for condition monitoring, fault diagnosis and fault prediction of critical aircraft components such as engines or flight control systems, which can support aviation PHM technology. In the research of PHM system, Boeing Aircraft Health Management (AHM) system [20] and Airbus Aircraft Maintenance Analysis (AIRMAN) system [21] has become a typical representative.

Currently, only the Health Management (HM) system is implemented in the most advanced Boeing 787 aircraft, and its PHM system is still in the research stage.

4. Conclusion

Domestic research on large aircraft PHM is still in its infancy, and a large amount of research investment is needed from concept to system design and implementation. It is foreseeable that with the continuous development of PHM technology today, its role in resource saving, efficiency improvement, system coordination and other aspects will become more and more important. Therefore, it is of far-reaching strategic significance to develop domestic IMA system, master the independent property rights of PHM system and reduce its dependence on imported technology.

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