Research on architecture design of UAV PHM system

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Abstract. According to the application requirements of state prediction and health management (PHM) technology in the field of UAV, this paper analyzes the functional requirements of UAV PHM system by referring to the research results and application experience of PHM technology at home and abroad and combining with the current situation of UAV support in China. Furthermore, this paper designs the architecture of UAV PHM system and introduces the workflow of the system in detail, which provides guidance and reference for the improvement of UAV comprehensive support level.

1. Introduction

With the progress and development of science and technology, the combat effectiveness of equipment is constantly improving, at the same time, the complexity of equipment is also increasing, and the scale and cost of equipment maintenance support are increasing rapidly. In order to reduce the burden of equipment maintenance and support, reduce the use and maintenance costs in the whole life cycle of equipment, military researchers in various countries pay more and more attention to the research of equipment maintenance and support, and promote the transformation of equipment maintenance mode from the traditional post maintenance and regular maintenance mode to condition based maintenance mode. However, as the technical support of this transformation, equipment testing and fault diagnosis technology has also experienced the evolution process from external testing to internal testing, and then to testability becoming an independent discipline, the proposal and development of comprehensive diagnosis technology, and the proposal and application of state prediction and health management technology [1]. Since PHM system was proposed, researchers at home and abroad have carried out a lot of research in many key technical fields, such as system health status assessment, life prediction, fault diagnosis, and formed a large number of valuable research results [2]. For example, PHM system has achieved good application effect in many projects represented by F-35 Joint attack aircraft [3], effectively reducing maintenance support costs, improving combat readiness and mission success rate.

As a new type of high-tech weapon system controlled by radio remote control equipment and its own program control device, UAV has many advantages, such as no risk of casualties, good mobility, good cost-effectiveness ratio and so on. It has been gradually valued by countries all over the world, and has begun to emerge in the battlefield. With the wide application of UAV in combat, how to use PHM technology to achieve UAV condition based maintenance and improve the comprehensive support level of UAV equipment has become a hot spot in UAV research. Many scholars at home and abroad have carried out many researches in this field and achieved a lot of research results.

Based on the research results and application experience of PHM technology at home and abroad, combined with the current situation and demand of UAV support in China [4], this paper studies and
designs the UAV PHM system to realize the evaluation, prediction and management of UAV health status, so as to improve the comprehensive support ability of UAV.

2. UAV PHM system function requirement analysis

PHM system generally should have the ability of fault detection, fault isolation, enhanced diagnosis, performance detection, fault prediction, health management, component life tracking, etc. [5]. Combined with the actual application of UAV, it is analyzed that PHM system of UAV should have the following functions.

2.1. hierarchical condition monitoring and evaluation

UAV system is a complex system composed of power, avionics, weapons and other subsystems. Due to the unmanned driving, in the process of its task, the staff can only judge the working state of the system through the information monitored by the sensors on it, so it is necessary to build a perfect multi-level state monitoring system covering the single equipment, subsystem to the whole system. By synthesizing all kinds of information and data to evaluate its own health status, the abnormal performance of UAV during task execution and other times can be found in time.

2.2. state prediction

In order to improve the maintenance support capability of UAV and realize the autonomous support of UAV, it is necessary to make full use of all kinds of information and data with the help of necessary means and measures to realize the reliable prediction of the equipment status of UAV system, so as to estimate the remaining life of the equipment and provide technical support for the implementation of preventive maintenance of UAV equipment.

2.3. maintenance decision and support

Based on the results of state prediction and fault diagnosis, the maintenance mode and level of UAV equipment are reasonably decided. Through the analysis of the existing maintenance tasks, the status of various types of maintenance resources, equipment maintenance requirements and other aspects of the maintenance system, the maintenance of UAV is reasonably planned, so as to ensure the effective combat effectiveness and maximize the utilization rate of maintenance resources and improve the level of equipment support.

2.4. intelligent fault diagnosis

For the abnormal phenomenon in the use of UAV, through the effective acquisition and use of all kinds of diagnostic information, with the help of a variety of diagnostic methods, with flexible diagnostic strategies to make a correct judgment and decision on the operation status and fault of UAV system, give fault information, and determine the location, type and severity of the fault, at the same time, automatically isolate the fault.

3. Architecture design of UAV PHM

As shown in Figure 1, the UAV PHM system is mainly composed of airborne PHM system and ground PHM system. Airborne PHM system is deployed on UAV, which is mainly composed of single equipment status information acquisition subsystem, subsystem information fusion and processing subsystem, UAV system status online evaluation subsystem, airborne status prompt and early warning subsystem, and onboard data management module in data storage and flow system. The main functions of airborne PHM system are UAV online data acquisition and storage, real-time state evaluation and early warning. The ground PHM system is deployed in UAV Ground remote control station and army base. It is mainly composed of data flow equipment and base database system in data storage and flow system, fault detection and isolation subsystem, condition evaluation and prediction subsystem, maintenance decision and planning subsystem and maintenance management subsystem.
The ground PHM system is mainly used for off-line data management, condition evaluation, fault detection and maintenance of UAV equipment.

3.1. single machine equipment status information acquisition subsystem
The single machine equipment status information acquisition subsystem is composed of sensors loaded on the single machine of each equipment on the UAV, in-flight test equipment and corresponding monitoring program. It realizes the acquisition and preprocessing of each single machine equipment status data, extracts the characteristics of each collected data, and compares with the design requirements to detect all kinds of abnormal phenomena in the operation process of the system in real time.
3.2. subsystem information fusion and processing subsystem
Subsystem information fusion and processing subsystem is used to evaluate the status of UAV subsystems. With the help of the state evaluation algorithm designed for the subsystem, the state information of each single equipment in the subsystem is integrated and sorted out, and the operation state of the subsystem is comprehensively evaluated.

3.3. UAV system status online evaluation subsystem
The UAV system state online evaluation subsystem is used to realize the UAV system level state evaluation. It fuses the multi-source state information data of each subsystem and preliminarily predicts the state, obtains the whole system state information, and compares it with the mission requirements to evaluate the current aircraft safety state and the impact of the combat mission.

3.4. airborne status prompt and early warning subsystem
The airborne state prompt and early warning subsystem is used to prompt the abnormal state and early warn the fault in the process of UAV task execution, and provides the preliminary fault diagnosis ability. According to the UAV state information, the preliminary fault reasoning is carried out, and the possible fault causes are sent to the ground station, so that the staff can carry out the fault repair preparation before the aircraft landing. In addition, the subsystem can also send the corresponding equipment status information to the ground according to the instructions of the ground station.

3.5. data storage and flow system
Data storage and flow rotor system is used for UAV state data storage and flow. In the process of UAV mission execution, airborne data and other support data are transferred to base database to form UAV status data warehouse.

3.6. condition assessment and prediction subsystem
Based on the status data, all kinds of support and design data in UAV data warehouse, with the help of relevant data fusion and status evaluation algorithm, the UAV equipment status is comprehensively evaluated. At the same time, combined with the specific situation of each system, one or more of the model driven prediction algorithm, data-driven prediction algorithm and statistical reliability driven prediction algorithm are used to predict the possible time point of each system failure.

3.7. maintenance decision and planning subsystem
The maintenance decision and planning subsystem is used to determine the maintenance decision of UAV equipment. Specifically, maintenance decision-making includes the determination of equipment maintenance mode (corrective maintenance or preventive maintenance), maintenance level (major repair, medium repair and minor repair), and the analysis of equipment maintenance requirements. According to the status of various maintenance resources and the arrangement of combat training tasks in the maintenance system, the paper comprehensively considers various factors in the maintenance, and plans a reasonable equipment maintenance plan with the help of the multi-objective decision-making idea, so as to ensure the reasonable maintenance of the faulty equipment, reduce the sudden failure of the equipment, and obtain the best maintenance effect.

4. Workflow of UAV PHM system
Each part of UAV PHM system cooperates with each other to complete various monitoring and support tasks of UAV. Its basic workflow is shown in Figure 2, which mainly includes five parts: online status data acquisition and preliminary analysis, data storage and flow, status evaluation and prediction, maintenance decision and planning, and fault diagnosis and maintenance.
4.1. **Online status data acquisition and preliminary analysis**

In the process of UAV's mission, the three-level state monitoring mechanism of UAV is constructed by the single equipment state information acquisition subsystem, subsystem information fusion and processing subsystem, and UAV system state online evaluation subsystem in airborne PHM system. The sensors installed on the stand-alone equipment collect the most original state data and test results. After data preprocessing, feature extraction and comparison with the feature requirements, the indicators of the stand-alone equipment are determined to be abnormal. The subsystem information fusion and processing subsystem fuses the status of each unit of the subsystem to get the system status. The UAV system state online evaluation subsystem fuses the state of each subsystem through the system comprehensive analysis of the state information of each subsystem, and uses the data during the task execution to carry out the trend analysis, so as to obtain the whole system state of the UAV at present and in the remaining time of the task execution, and judge whether the UAV has abnormal state or fault phenomenon at present. If there is any abnormal phenomenon, the influence of the fault or abnormality on the combat mission can be judged by comparing with the mission requirements.

4.2. **Data storage and transfer**

During the task execution, while analyzing the state information at all levels of the system, the original state data collected by sensors, each equipment, intermediate results of evaluation and processing at all levels, abnormal or fault information are also stored in the airborne data card, so as to provide data and...
information support for the UAV off-line state comprehensive evaluation. When there is a fault or abnormal phenomenon in the system, which may endanger the mission, the airborne status prompt and early warning subsystem sends the abnormal or fault information to the ground station through the data link at the first time, and carries out the preliminary fault diagnosis and reasoning at the same time, and sends the fault reasoning results to the ground along with the abnormal or fault information for the decision-making reference of the ground station staff. When necessary, the ground station staff can obtain more detailed status information by sending relevant instructions to the airborne status prompt and early warning subsystem. If the UAV status does not affect the task execution, the UAV can download the status data to the ground data in the following two ways to avoid the task delay caused by data download after returning to the base.

(1) When the mission is urgent, such as when the UAV needs to carry out the mission again after returning to the base to replenish weapons in wartime, the onboard data card can be directly replaced, and the replaced data card can be inserted into the ground reader to read out the data.

(2) When the task is not very urgent, the data can be downloaded to the flow equipment by using the data flow equipment, and then transferred to the ground database system.

4.3. condition assessment and prediction
In order to reduce the occupation of on-board computing and storage resources, UAV on-line condition monitoring and evaluation only completes basic index judgment, anomaly detection and preliminary state prediction, while ground PHM system provides perfect function of condition evaluation and prediction. After the UAV returns to the base to download the data, the state assessment and prediction subsystem will update the state assessment results of the UAV randomly based on the various design and use support data of the UAV. At the same time, different prediction methods are used to carry out the state prediction according to different conditions of each equipment. For example, for the UAV fuselage structure and power supply system, the failure mode and failure mechanism are relatively simple, and the single machine or subsystem with degradation model is used for performance prediction. For the single machine or subsystem with rich and complete historical work data, fault analysis or simulation experiment data accumulation, the data-driven method can be considered to carry out performance prediction, and the hidden information and equipment development trend can be mined through various data analysis and processing methods. For the single machine or subsystem with typical statistical law in historical fault and experimental data, the corresponding fault probability density function can be obtained by analyzing the statistical data, and the equipment state development can be predicted by this statistical reliability method. In practical application, for the equipment performance prediction that meets the requirements of the above methods, we can use a combination of multiple methods to carry out performance prediction, so as to estimate the failure time of each equipment and obtain its remaining life.

4.4. maintenance decision and planning
For the UAV equipment that has failed, according to the equipment failure information and subsequent task arrangement, with the participation of decision-makers, the maintenance level of equipment repair maintenance is analyzed, and the equipment maintenance requirements are evaluated. For the UAV equipment without failure, based on the results of UAV off-line state evaluation and prediction, the influence of equipment failure point on combat training task is analyzed, and the reasonable preventive maintenance opportunity and maintenance demand are determined.

After obtaining the maintenance decision results, the system reads the equipment maintenance requirements, constructs the maintenance task model, and defines the maintenance resource requirements. Then read the maintenance system information, get the maintenance system operation information, as the boundary condition of planning, comprehensively consider the maintenance time, maintenance cost, equipment combat effectiveness, equipment reliability and other optimization objectives, carry out multi-objective decision-making planning for maintenance work, and get the comprehensive optimal maintenance plan.
4.5. fault diagnosis and maintenance
In the maintenance system, the fault detection and isolation subsystem provides diagnostic technical support for maintenance personnel, and the maintenance management subsystem provides resource coordination and progress monitoring means for maintenance management personnel.

First of all, after the maintenance task is assigned to the maintenance system, the maintenance management personnel use the maintenance management system to coordinate the required maintenance resources, and carry out comprehensive scheduling of the tasks in the system. In view of the traditional maintenance support system has formed a maintenance management mode with process steps as the core, the maintenance management system guides and supervises the development of various maintenance processes by issuing electronic work orders to each maintenance station. Then, according to the requirements of the work order, the maintenance staff carry out fault diagnosis and maintenance with the support of the fault detection and isolation subsystem. Finally, after the maintenance work is completed, the maintenance department will return the equipment to the user department, and import the data generated in the maintenance process into the database to update the UAV equipment support database information.

5. Summary
Taking UAV as the research object and referring to the research results and application experience of state prediction and health management at home and abroad, this paper analyzes the functional requirements of UAV PHM system, and studies and designs the architecture and work flow chart of UAV PHM system, which provides design reference for the application of UAV PHM technology. However, many technologies involved in PHM system, such as system level condition assessment and prediction of complex equipment, comprehensive fault diagnosis and so on, are not fully mature, and there are still many problems to be solved in application. Therefore, in the follow-up research, we should continue to pay attention to the advanced research results and successful application experience at home and abroad, strengthen the research of various basic technologies, promote the application of various technologies in PHM system in the field of UAV support, and improve the comprehensive support level of UAV.

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