THE INTEGRATION METHOD OF FAULT DIAGNOSIS AND HEALTH ASSESSMENT FOR UAV SYSTEM

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Abstract

This paper systematically dissertate the engineering method, system structure, integrated reasoning model and the building flow of design flow of fault diagnosis for UAV system, puts forward a realizable method of integrating fault detection, diagnosis and assessment which bases on advanced sensor technology, delaminating logic and multi-information intelligence model technology. And a application demonstration has been gave in this article last.

Introduction

UAV becomes the research focus of aviation field in recent years, and it has many advantages when compared with manned Vehicles. However, when there is a failure, no detection and correction measure can be done during operation, UAV would be exposed to catastrophic consequence. Therefore, study is very necessary to detect and diagnose the fault, evaluate the healthy state during the operation of UAV. Research in testability, condition monitoring, redundancy and reconfiguration design is the foundation for failure detection and diagnosis, also, it is the basis to study the method of failure diagnosis and health assessment.

1 Basic Theory

1.1 Detection and Diagnosis and Prognostic Heath Management

Detection and diagnosis is a progress that making use of testability, built-in test (BIT), manual test, technological information and other ways and means, to inspect the status and fault information of tested object. Using the method of system engineering and trade-off, Integrated Diagnosis make use of the results of detection and diagnosis, fulfill hardware, software, technological document of the diagnosis that the aircraft request, so that achieve the requisite diagnosis ability cheaply, detect and isolate all the faults known or anticipated.

The core of integrated diagnosis is that to integrate every unit under test (UUT) and cooperate with each other. Integrated diagnosis includes the integrating of every diagnostic element, every maintenance level and every phase of life cycle.

The integration of every diagnostic element make use of the information of current diagnosis data and distribution of diagnostic request and balance analysis, satisfy the best compages of every diagnostic element of diagnostic request of every product's level at the lowest cost. The integration of every maintenance level requests consistent ability of test and diagnostic of every maintenance level. Diagnostics embedded on board and ways of diagnostic can detect and analyze the known fault at 100%, can isolate fault to line replaceable module at the lowest alarm rate, and can let line status messages and fault messages into automatic test system. The base level diagnosis and maintenance impose on automatic test equipments come true, that build of multi-ATE witch work independently and setup based on every material UUT mostly.

Prognostic and Heath Management (PHM) is a new technology developed upon the maturity of testability, BIT and integrated diagnosis technology. It adopts advanced sensor technology, uses the traditional fault character detection technology furthest, and integrates advanced software modeling, and attains exactly the result of fault detection and isolation which alarm rate tends to zero, with the help of much arithmetic and intelligent model, could diagnose, inspect, predict and manage the state of the aircraft. PHM is a more extension of BIT and diagnosis and status monitor, whose mostly technique factor is a conversion from status monitor to status management. The key of PHM make use of advanced sensor (such as low power wireless integration micro sensor and wireless micro electromechanical system sensor and vortex sensor, and so on.) and much arithmetic (such as Fourier transform, Gabor transform) and intelligent model (such as blur logic, nerve network, expert system, and so on.) to predict and inspect and manage the state of the aircraft, which upgrade the ability of testability and BIT. PHM can realize enhanced diagnosis, detect and isolate the fault of system and components and unit exactly, judge the disabled status of system, and to manage the status of the aircraft's system, by dint of system model and related corroboration data and information fuse technology.

Therefore, the primary function of PHM include fault detection, fault isolation, prediction residual useful life, life track of components, trend track of capability degrade, fault selectivity report, assistant decision-making, resource management, tolerant system, information amalgamation, reasoning and information management.

Fault diagnosis and heath evaluation are the important technology basic of PHM. PHM is an incorporate system that make on-board and off-board uniform, it adopts delaminate reasoning structure so that the aircraft could synthetically apply the technology of fault diagnosis and prognostic from every component up to all the system.

1.2 PHM and Reliability Engineering

PHM is an advanced and integrated diagnosis technology based on testability. The design of reliability, maintainability, testability and supportability is the basis of PHM.

FMECA and FTA is the analysis and design basis to make diagnosis concept project, define test requirements and system components or functional items that needed to be diagnosed and monitored. Maintainability design and analysis provides input for diagnosis functions classification, for airborne and ground functions classification. Testability design and analysis (including diagnosis requirement, test classification, testability prediction, embedded and exterior testability analysis etc.) provides input for hardware and software PHM design of system, assembly/LRM. The outcomes that based on operation requirement analysis, compare analysis, evaluation and tradeoff analysis of support system concept, RCMA, level of repair analysis, will provide input for PHM diagnosis resource configuration and the interface between PHM and support system.

By detecting and locating system fault correctly, design such as reconfiguration, redundancy, self-repair can be adopted to improve the mission reliability of UAV. Also, fast fault detection, recognition and location can reduce fault detection time, maintenance time, halt diagnosis time, logistics delay time and maintenance wait time. Moreover, improvement of BIT integrated performance, fault integrated diagnosis ability can carry out real time airborne monitoring, fault diagnosis, fault prediction and fault prognostics. Furthermore, condition based maintenance would replace corrective maintenance and hard time maintenance, to reduce the procedure of maintenance and supply support and the requirements for ground test equipments and maintenance crew, lessen the logistic support scale, implement the integration of diagnosis, maintenance and logistic support, improve the supportability of system.

The relationship of reliability, maintainability, testability and supportability is referred to Fig.1.

1.3 Fault Diagnosis and Health Assessment System

Integrated fault diagnosis and health assessment system is based on system framework and related technology of diagnosis and assessment. The system framework of integrated fault diagnosis and health assessment

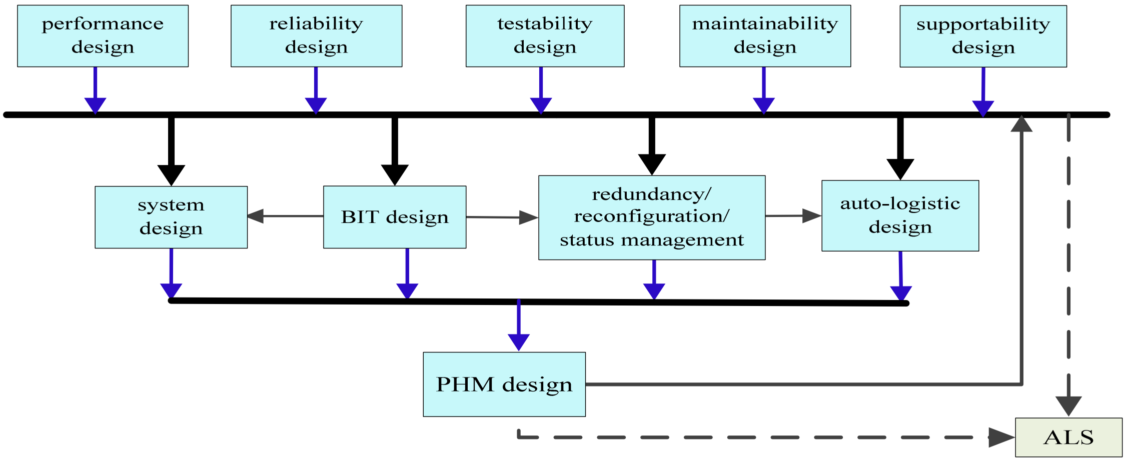

Fig. 1 PHM Design and Reliability Engineering

is based on MIMOSA-OSA-CBM and MIMOSA-OSA-EAI, it is an open system framework. The integrated diagnosis technology based on BIT includes the system framework from witch fault function is created, and the system framework from witch test page layout is created, and fault integrated analytic technology.

System structure and method related integrated fault diagnosis and health assessment system, include system structure consisted of seven layers, which are system methods, sensor and perceptive strategy, data obtain and characteristic acquire, fault test diagnosis, health assessment and failure effect, support of maintenance and mission decision , and denotation.

The system design method related includes seven procedures, which is design and trade-off, FMECA, test point design, data collection, data analysis, arithmetic development, implementation and validation。

The techniques related Integrated fault diagnosis and health assessment, include:

1) Fault diagnosis technology based on reasoning. This diagnosis technique is respectively based on historical data, real time data driven and physical model.
2) Prognosis technology, based on model prognosis and data prognosis.
3) Decision-making technology, failure and maintenance relating technique, maintenance decision and denotation technique, maintenance support drive technique.

2 Integration Diagnosis and Health Assessment Method

2.1 Design Flow of Fault Diagnosis

The design of PHM system is to structure the continuing process of status monitoring, failure diagnosing, evaluating of the status and failure influence. Based on research and practice, we've proposed a design flow of status monitoring and failure diagnosing.

1) The capability requirements of PHM system have been confirmed , Then the system demands would be assigned to the subsystems, modules, meanwhile the on-line and off-line demands have to be set up;

2) Developing the design and analysis of reliability, maintainability, testability and supportability, especially the testability/BIT design of the module, assembly and subsystem;

3) Finding out the key part or key point through FMECA.

Simultaneity reliability module, the FMEA or augmented-FMEA would be developed to find out the key part or key point of the system, to analyze the failure modes and combination characteristics of the failure modes and test method, to distinguish the diagnose modes of BIT or system integration.

4) Finding out the characteristic quantities of diagnosing and status monitoring management.

According to the relation model FMEA and engineering experiences and mission demands and environmental influences etc, the characteristic quantities under test and management of the systems and assembly would be confirmed. Synthesized parameters, such as capacity, failure characters, life-span, mission parameters and environmental parameters etc are preferred and character inspection and fitting are developed. The signals under monitoring and testing should be sorted by importance and processed in a different way.

5) Sensor disposal and data testing technic.

By balancing reliability, fee, dimension, weight and power in sequence, testing methods and sensor precision demands and cubage reducing of the products are being studied to confirm the sensor quantity and sensor disposal manner with the least data measurement demands. Technology of data measurement and pretreatment and low SNR signal distilling are synthesized to acquire sufficed source data.

6) Design the model of diagnosis and monitoring.

A synthesized diagnosis and design is a method by developing the reasoning model to enhance the failure detecting and isolation. The reasoning model is the key to the synthesized diagnosis and evaluation. Currently, physical model and statistics model and knowledge system model (expert system based fuzzy logic system etc) are synthesized together through different approaches to form the commixed model, to meet the demands of the system monitoring and diagnosis. There're three major models for reasoning, which are diagnosing reasoning model and prognosticating reasoning model and abnormity reasoning model. These three basic reasoning models can be used in both the air system and ground system.

7) Assembly/system structure and interfaces defining.

According to the airplane system requirements, failure diagnosis and status monitoring system structures, data expression and transmission criterion, assembly and system interfaces, on-vehicle and ground interfaces are defined, the hardware and software functions for failure diagnosis are plot out, the way of detection, transfer and display control are designed. To fulfill the demands, standard TM bus can be collocated in the system structure definition. In a general way, the system testing and health monitoring structure based on the three reasoner are shown on the Fig.2.

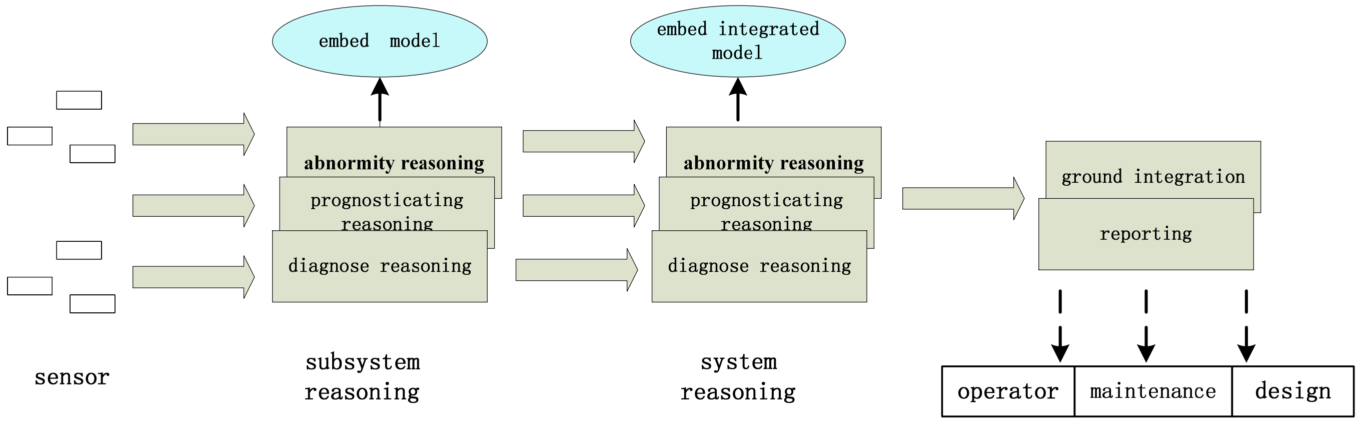

Fig. 2 System Testing and Health Monitoring Structure

8) Validation and iterative

Fault diagnosis and health evaluation method design is a synthesis and model selection from the multifold methods in existence. Thus, failure diagnosis design is a gradually mature process, it becomes particular in a iterative way and finally becomes perfect. During this process, the model and arithmetic adopted need to be validated.

2.2 Demand Assigning and Data Measuring

The important point of fault diagnosing and health evaluating is assigning the demand of diagnosing and evaluating to the appropriate levels. The content is just considering the demand is reached in aircraft or in ground control system, and fractionizing the data is dealing on-line or off-line. Whether the data is obtained conveniently and felicitously, and which standard for exchanging information should be abided, and how to realizing the technology project, these contents must be considered in the mean time.

For example, the pretreatment of data, the distilling of character, the classifying of data, the evolvement trend of fault, and the injunction of maintenance should be assigned in the aircraft. While the assistant identifying of character, FMECA, history data, and useable resource should be dealing in the system on the ground (Fig.3).

4) Environment and reliability: the capability of adapting temperature, humidity, dust and cauterization, the reliability of system self.
5) Cost: the cost of system will rises with the large-scale using of sensors.

In the diagnosis system, the data and eigenvalue obtained by data measuring system are transferred as BIT data and original data. It is restricted by the flux of the net between aircraft and systems on the ground.

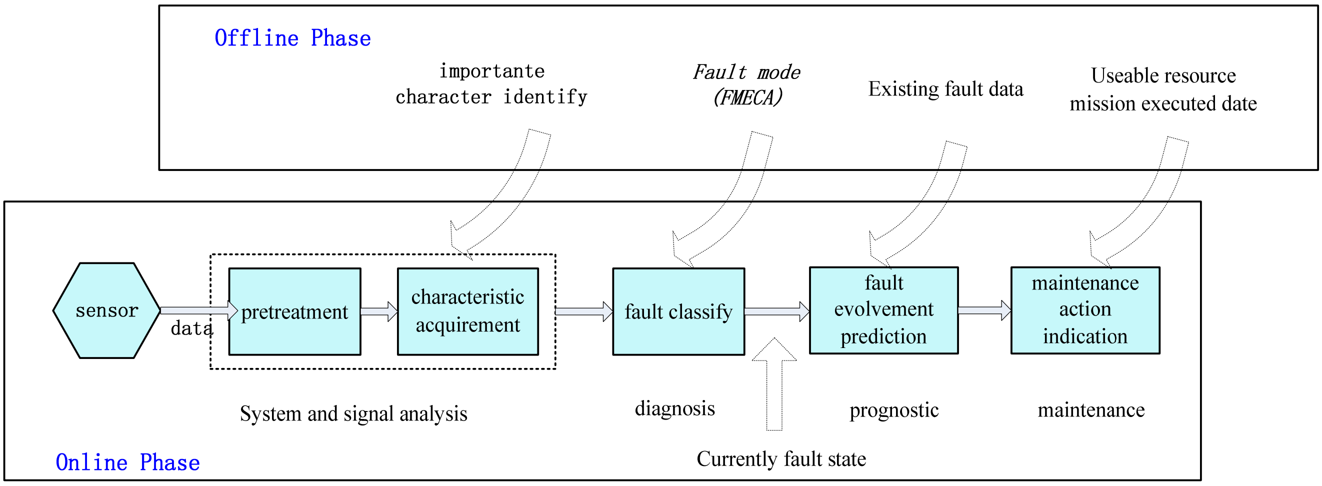

Fig. 3 On-board and off-board testing requirements distribution

When demands are assigned, the next job is obtaining the data using the sensors. The base of data measuring is the sensor. To realizing the object of fault integrated diagnosing, the sensors should be distributed exactly and the distributable method should be rightly, then the strategy of apperception should be confirmed. The styles of sensor contain mechanical/ structural sensor (e.g. accelerometer, strain gauge, ultrasonic sensor), temperature sensor, electric sensor, optical fiber sensor, etc.

The sensor must be enduring, robust, precise and sensitive. The build of sensors system base the following five sides.

1) Capability: precision, scope, error, conversion efficiency, linearity, etc.
2) Confine of system: consume of power supply, storage size of data, capability of disposal, etc.
3) Physical property: size, weight, encapsulation, installation, etc.

2.3 Integration Diagnosis and Health Assessment

2.3.1 Online Fault Monitoring and Diagnosis

Based on electronic equipment BIT and sensor design of electromechanical equipment, data and information are apperceived, the eigenvalues are captured. Then, the captured data of the equipments is transferred to the superior level. If data driven diagnosis method is adopted, digital signal would be processed at this level. Based on the character of the digital signals, the signals are transformed to found eigenvector. Diagnosis methods like fuzzy logic and expert system and NN are adopted to confirm the faults, and the faults are sorted to be transferred, meanwhile testing signals on the ground are immitted to improve the precision of the diagnosis. Subsequently, fault or failure is confirmed on the ground system. According to the types of the faults, different measures like fault display and fault data record and storage etc. are adopted to make sure that the data is processed in a centralized way or the maintenance claim is fulfilled. If the diagnosis method based on models is adopted, the data produced by the equipment at this level would be processed by method like Kalman filter and NN etc. Data by repeated statistic at the underling equipment level is processed by system models and then fault is judged and confirmed. Similarly, the fault is sorted and transmitted. In the same way, the precision level can be improved by immitted testing signals on the ground. After the fault or failure is confirmed on the ground system, the followed processing method is similar to data driven diagnosis method.

Mature BIT or special mature sensors are applied in online fault monitoring and diagnosis, ulteriorly, the precision model and judgement for data are adopted. Compared to common BIT, more accurate online fault monitoring and diagnosis to the equipment and subsystems can be realized, they are the base of the judgement and management of the health status of the system. On line fault monitoring and diagnosis are shown on Fig. 4.

preplanned definition. Fault modes (fault functions) database should be defined in advance for synthesized diagnosis based on fault functions. Based on this database, rules defined beforehand are made. These definitions are all based on detailed FMECA results and supplements added by experiences. The core of the rules is the corresponding relation definition between certain condition and fault conclusion. It is shown on the table 1.

Table.1 Relation defining of condition and fault conclusion

condition	fault conclusion
IF (leakage coeff. L is large)	THEN (fault is the pump leakage)
IF (motor damping coeff. D is large) AND (export-press-coeff. Of the cannulation is low)	THEN (fault is excess cylinder friction)
… …	… …

Synthesized diagnosis process based on fault functions:

1) Set up datasheet of monitored parameters, fault function database and index table in advance.

2) Search the fault function database and pick-up object-related data which need to be monitored.

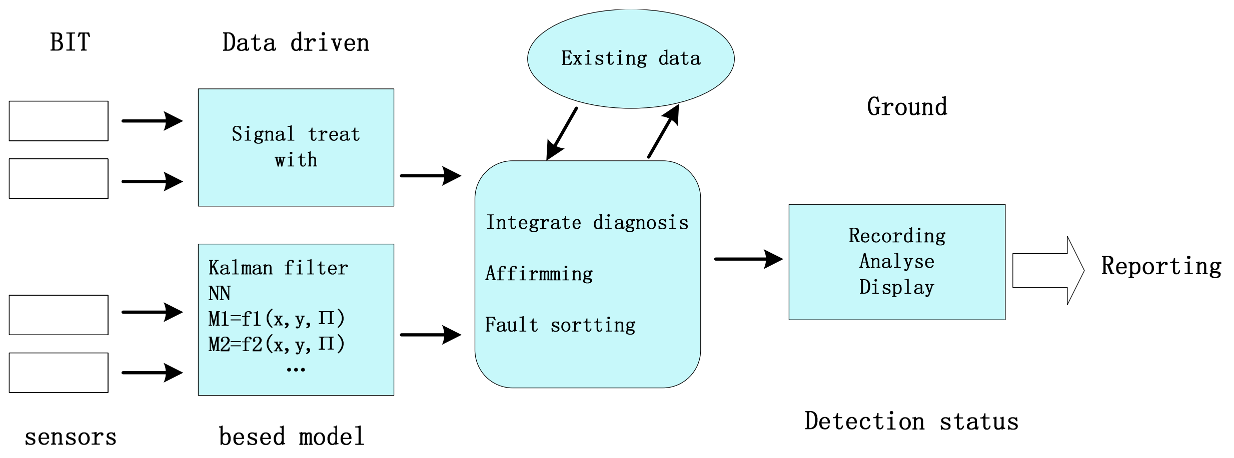

Fig. 4 Online Fault Monitoring and Diagnosis

2.3.2 Synthesized Diagnosis based on Fault Functions

Fault function is a method applied in sorting and decision-making based on fuzzy logic. It use reasoning technic witch based on

3) Monitoring the data, analysis and calculate the changing data according to the fault function index table, a ‘T’ returned stands for a special ‘fault’, meanwhile ‘E’ stands for to be decided.

4) Information relating according to the results by analysis and calculation.

5) Fault information Storage and report.

2.3.3 Health Assessment of System

System health evaluation is the synthesis of the diagnosis and monitoring of data results, it is a final judgement by the system makeup. This article defines a relation model matrix to evaluate system health state. This matrix expresses a configuration which is related to the system health. The element model in the matrix comes from section2.3.1、2.3.2 etc. in this article. For example, there's a system which is made up of 10 subsystems or equipments, and there're 5 indexes for health evaluation, the relation model matrixes listed below:

$$A = \{a_{ij}\}$$

$$a_{ij} = (s_{ij}, m_{ij}, r_{ij}) \qquad 1 \le i \le 5, 1 \le j \le 10$$

s_{ij} fetches one of the three values which stand for normal or fault or fade; m_{ij} fetches one of the three values which stand for data driven or model or fault function; r_{ij} fetches 1 or 0 which stands for the relation between s_{ij} or a_{ij}.

A_0 is supposed to be the baseline index of health, then $A \le A_0$ means a health state of the system to be.

The evaluation is based on system, and the ground system according acquired baseline data and the real functioning state data (BIT data, the data analyzed and calculated by fault function) judge the health state of all system. Special system baseline indexes are set up, and the information amalgamation results can be the measurement index. At this level, for most systems, collated judgement and state judgement and management are made. The fault diagnosis is based on the comparison between basic data like rating or admitted limitation and the tested state. Within the admitted limitation, it is judged as normal, while beyond the admitted limitation, it is considered to be the fault. Considering the uncertainty of fault character, the manifold uncertainty information amalgamation based on the evidence theory is adopted to improve the reliability of fault mode and state discrimination.

3 Application Demonstration

For validating basal technique procedure and method, a typical simple engineering application is chose as a demonstration that adopts the method in this paper. The implement process for demonstration software is shown in fig.5. The demonstration system validates integrative diagnosis and evaluation function, diagnosis model and arithmetic (consequence base on rules)， software, interface, maintenance information, PHM flow etc, by demonstration software and simulation. In this paper, aiming at a part of flight control for UAV VMS system, a closed loop control system formed by control processor and actuator is chose, and two-redundance system

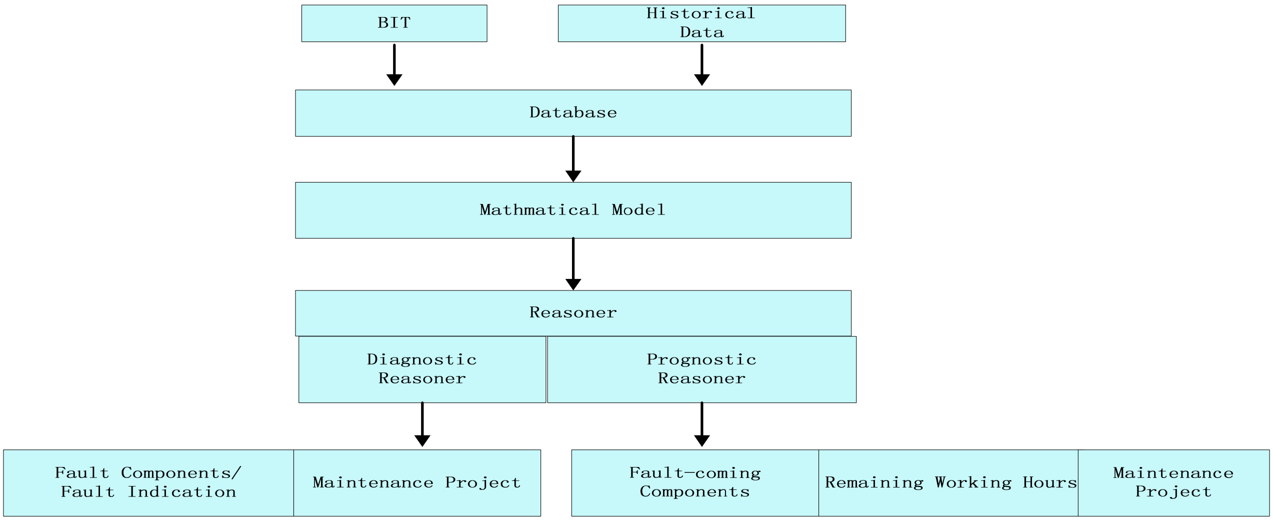

Fig. 5 Diagnostic and Prognostic Reasoner Cases

is used for diagnosis and prognostics.

The implementing process of the casus is: collecting real-time data by simulation BIT, and reading exciting failures data of actuator by ground station at the same time, and then, acquiring correlative data from data-base by relevancy mathematics model for failures mode, then displaying fault alarm and maintenance precept by transferring reasoners, and then prognosticating the remnant time that the actuator subassembly will leak, finally presenting the scheme for changing actuator subassembly in advance. The functions implemented by the demonstration system are:

1) BIT: Set three BIT modes, PUBIT, IBIT and PBIT. PUBIT and PBIT run automatically when demonstrating. PUBIT run so long as the system start, and then, PBIT run automatically and periodically, IBIT run when press a button.

2) Redundant management: the demonstrate system is set as two-redundance system for monitoring contrastively.

3) When BIT detect the failures or redundant management overrun (immovable limitation is 10%), intelligent diagnosis based on model monitor is triggered automatically. The diagnosis reasoners give the output as the following: failure subassembly to be identified and isolated, display of failures, maintenance percept or maintenance behavior to be suggested, restriction and influence for implementing mission for failures.

4）The trigger for diagnosis reasoners and prognostics reasoners. Redundant management and BIT limitation are disjoin to two ranks for simple, the first rank is failure, the diagnosis reasoners will be triggered when the first rank is overrun; prognostics reasners will be triggered when 5% of the second rank is overrun or the stated time is overrun, and then calculate the remnant life by illegibility artificial intelligence.

4 Conclusion

Based on the research of the relationships between testing and diagnosis, PHM and reliability engineering, a synthesis method of fault diagnosis and health evaluation is proposed in this article. According to the example, it is mainly validated that the method flow and the requirement assignment and the synthesis application of evaluation method are acceptable. All these research results provide a basic method for the general development of UAV system fault diagnosis and health evaluation. Subsequently, the research on the set up of synthesis diagnosis model of the specific systems and the research of the relation model matrix and of index matrix for system health evaluation should be carried out.

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