REVIEW AND PROSPECTS OF INTELLIGENT DIAGNOSIS TECHNIQUE FOR SPACECRAFTS[1]

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Abstract In this paper the failure records of spacecrafts over the world are reviewed to confirm the urgency of the diagnosis of faults. The special features of the dignostic technology for a spacecraft are discussed, and accordingly the problems of diagnostic technology for a spacecraft system are reviewed and prospected such as: the strtegy and architecture of the intelligent diagnostic system, the hierarchical structure of the knowledge model, the inexact reasoning and heuristic reasoning, the distributed diagnostic technology and so on. Finally, the prospects of the intelligent diagnosis technique for a spacecraft are reviewed..

1. The Spacecraft safety assurance

1.1 Diagnosis -- an Urgent Mission for a Spacecraft

The health management is an extremely important mission for a spacecraft. To achieve reliability and safety of a spacecraft, although every effort has been paid in the phase of design and manufacturing, miserable failures are still unavoidable. A miner malfunction of an element of the system may cause a large failure and even a vital accident of the whole system. That is why attentions are paid to study how to predicate the faults and how to find the

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sources of faults to avoid development of failures. In this way diagnosis plays a very important role in health management of the spacecraft.

1.2 Some Failure Records

In Fig. 1 and Fig. 2 an incomplete statistics is given to show the failure rates of spacecrafts over the world. We see that in the early years the failure rates of some lauching vehicles and satellites were very high. Recently safety is highly raised by use of highly qualified design and manufacturing, but also the extensive adopt of advanced diagnostic technique gives important contribution.

Tab. 1 The Failure Rates of Some Launch Vehicles

Launch Vehiles		Period	*No.Launches*	*No.Failures*	*Fail. Rates*
	Vanguard	*1957.12--1959.6*	*11*	*8*	*72.7 %*
	Juno-1 and 2	*1958.1--1961.12*	*16*	*8*	*50 %*
	Thor Series	*1958--1983*	*388*	*51*	*13.1 %*
US	*Delta*	*1960--1993.6*	*220*	*12*	*5.4 %*
	Atlas Series	*1960--1990*	*185*	*30*	*16.2 %*
	Titan Series	*1964--1986*	*122*	*13*	*10.6 %*
	Saturn Series	*1961--1973*	*32*	*555 Faults*	
	Moon	*1958.5--1960.4*	*12*	*9*	*75 %*
USSR	*East SL--3*	*1960.1--1988.12*	*148*	*3*	*2 %*
(Former)	*Union SL--4*	*1963.11-1962.12*	*991*	*12*	*1.2 %*
	Proton Series	*1965--1988*	*169*	*12*	*7.1 %*
	Zenith	*--1993*	*26*	*6*	*23 %*
ESA	*Ariane*	*1979.12--1994.1*	*63*	*6*	*9.5 %*
Japan	*N1*	*1975.9--1982*	*7*	*1*	*14.3 %*
China	*Long March*	*1964.6--1992.3*	*31*	*3*	*9.6 %*
India	*SLV--3*	*1979.8--1993.9*	*4*	*2*	*50 %*

Tab. 2 Failures and Faults of 350 Satellites in 1958--1978

	Failures and Faults	*Number*	*Rate*
1	*Failures*	*43*	*12.3 %*
2	*Faults*	*267*	*76.3 %*
3	*Without Report*	*40*	*11.4%*

1.3 Historical Aspects

Since the eighties a lot of diagnostic expert systems were developed for various satellites, space vehicles, space shuttles, etc., the typical ones were the

Failure Diagnosis Prototype *DR*[1] and the Failure Recovery Planning Prototype *Rx*[2] for the early Space Station Project *Freedom* ,which is the basis of the *International Space Station*[3].

The United States Congress in Public Law 98--371, dated July 18, 1984, states that NASA will identify 'specific space station systems which advance automation and robotics tecnologies, not in use in existing spcecraft,and that the development of such systems shall be estimated to cost no less than 10% of the total space station costs'. Recognizing the need of NASA's mission require-ments, the Office of Aeronautics and Space Technology granted approval in Nov. 1985 for the systems Autonomy Demonstration Program, and a series of 'four milestone Demonstrtions' were envissioned[4][5]showing the course of development of diagnostic technology for spacecrafts in nineties.

2. Special features of dignosis for spacecrafts

Comparing with technique of fault diagnosis for a ground equipment, the technique of diagnosis for a spacecraft is a more complicated and difficult task with special features such as:

(1) The high safety assurance requirements demand high accuracy of diagnostic results and even high reliability of diagnostic system itself;

(2) Since the spacecraft is a complex large-scale system, it consists of a series of subsystems coupled closely with respective functions and mutual relations. Consequently a distributed and hirarchical architecture is reasonable for the diagnostic system;

(3) Along with the variation of flight mission of the spacecraft and the variation of space environment, the configuration and structure of the spacecraftare regulated continueously, and the fuel and resources are consumed redularly, thus the system has to be considered as a time-variable system;

(4) The constraints of space and weight in a spacecraft lead to a compact diagnostic system with limited functions;

(5)The constraints of setup of sensors and accordingly limited information available increase the difficulty of diagnostic technique;

(6) The human experiences for failure diagnosis of spacecrafts are still very limited compared with diagnosis for ground equipments that needs further research on theory and practice of dignostic technology.

3. The Architecture of an Intelligent Diagnostic System for a spacecraft

3.1 The Onboard and Ground Diagnostic Systems

Because of the constraints of space and weight of a spacecraft, the diagnostic systeems are partially set on ground, and the signals from the sensors on board are first transmitted to the Data Center, then transmitted to the Ground Diagnostic Center. For various spacecrafts the arrangement of the onboard and ground diagnostic systems are different, for a large space station the onboard diagnostic system posesses the ability of autonomous diagnosis, but for a small satellite the diagnosis is performed mainly on the ground.

3.2 The Hierarchical Structures of a Diagnostic System

The spacecraft system is composed of a series of subsystems which are in turn composed of components, these components are still composed of parts and elements that presents a character of hierarchy and inheritance structure.

The model of hierarchy and inheritance is not only for physical structure but also for the status (by sensors), functions and failures events. Every one of these four aspects has its hierarchy and inheritance structure, but thy have mutual corresponding relationship each to other. This character determines the hierarchy and inheritance structure of the diagnstic system, and also the hierarchy and inheritance structere of the diagnostic technology such as the knowledge-base structure and the reasoning strategy,and so on.

3.3 The Distributed Architecture of the Diagnostic System

The spacecraft system is a complex large-scale syatem, its diagnosis is a very complicated procedure. Since the spacecraft is composed of subsystems, the distributed architecture of the diagnostic system distributes diagnostic mission to expert subsystems, and the global diagnostic system carries out the diagnostic mission management including the task decomposition, task distribution and task coordination for subsystems whose status and behavior relate and affect each other. After the submissions are solved, the solutions of submissions are synthesized to give final diagnostic conclsion of the spacecraft system. In Fig. 1 an example of distributed architecture of intelligent diagnostic system is shown to illustrate the diagnostic procedure and the relationship of the global system and the diagnostic expert subsystems.

4. The Technique of Intelligent Diagnosis for a Spacecraft

4.1 The Knowledge Representation

The method of knowledge representation is the core of the diagnostic technique . There are a lot of methods of knowledge representation and consequently there are a lot of corresponding diagnostic techniques. The diagnostic techniques that can be used to the intelligent diagnosis for a

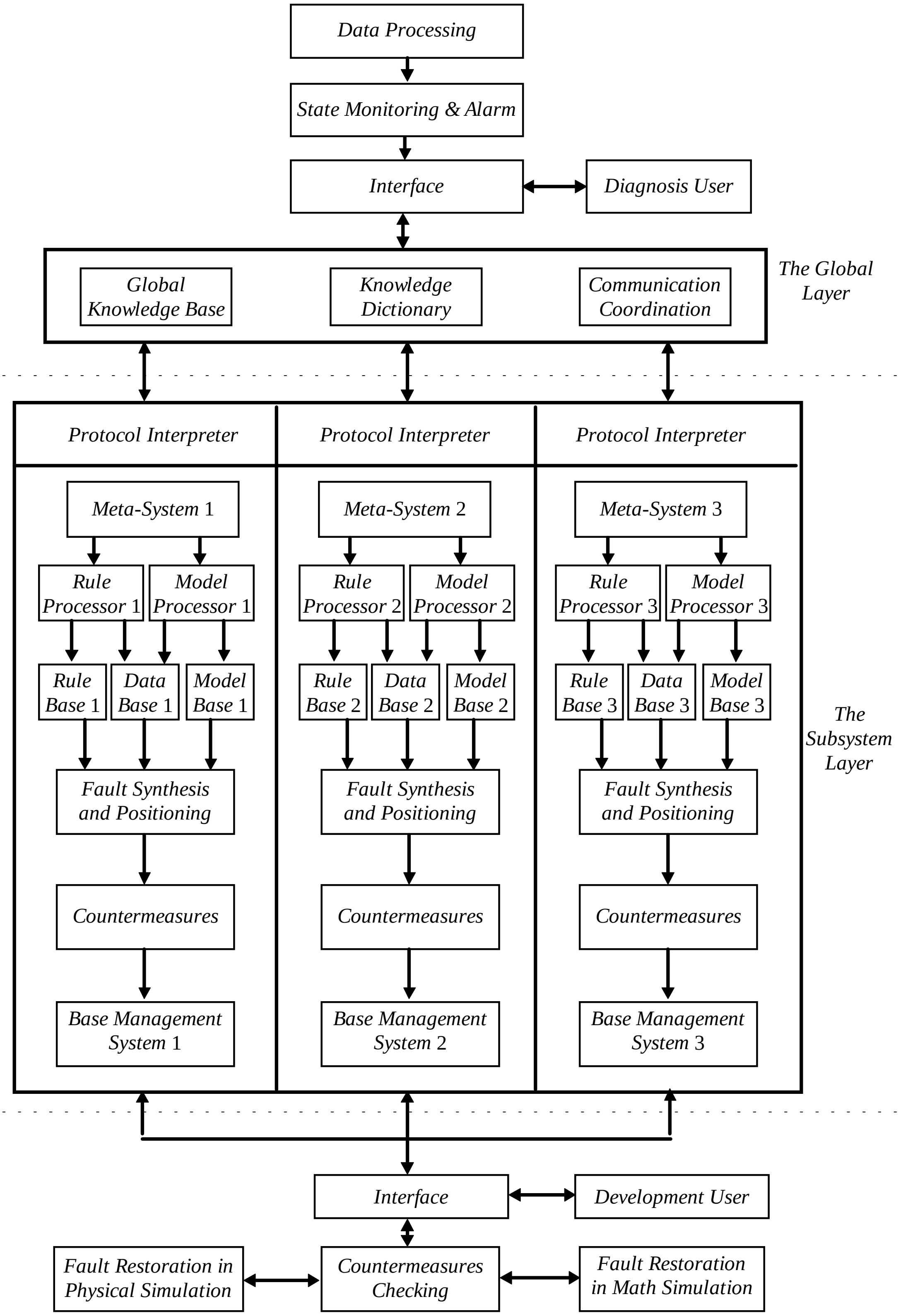

Fig. 1 The Architecture and Structure of a Distributed Knowledge-Based Global Diagnostic System for a Spacecraft

diagnostic techniques that can be used to the intelligent diagnosis for the spacecraft are the diagnostic technique based on rule reasoning, on case studies, on semantic networks, on frame-matching, on predicate reasoning, on qualitative models, on quantitatives models and on artifical neural network, and so on .

Roughly speaking, the above mentioned diagnostic techniquesfall into one of the two categories: rule-based techniques or model-based techniques. Diagnostic systems with rule-based knowledge representation encode expert's knowledgeabout the diagnosis problem as declarative rules. These systems have been quite successful, but it is difficult to maintain consistency when updating or adding to the rule-base of such systems. The problem will even more serious for spacecrafts because the human experience and diagnostic rules are seriously insufficient . Diagnostic systems with model-based knowledge representation usually simulate the system being diagnosed and find faults by comparing the simulation results with actual data. The simulations are usually quite time-consuming and the diagnosis problem could become quite complex when multiple failures are present. As for the spacecrafts, since it covers various areas,the above mentioned various techniques shouldbeincorporated .

4.2 The Parity Space Approaches to Fault Diagnosis[7]

The focus of attention in diagnosis in recent years has been on robustness methods for fault detection and isolation, following a growing awareness of the need for more reliable systems. Robust methods are able to detect incipient (soft or small) faults in system components, before they are manifested as problems requiring either human operator or automatic system intervention (acommodation or controll reconfigulation). The parity space approach is a powerful method to meet this demand. It is a kind of model-based diagnostic technique. The parity space is a space in which all elments are residuals or parity vectors having the similar meanings with the 'parity checks' in computer software reliability. The model-based parity space fault detection and fault isolation process consists of two stages including 'Residual Genration' and 'Decision Making' (Fig. 2). The algorithm for use in the real-time applications based only on input-output processing of all measurable signals. It has the advantages of isolability of specific faults and robustness with respect to uncertainties. This technique has the potential in spacecraft diagnosis applications.

4.3 The Knowledge Acquisition Problem

The knowledge acquisition is a bottle-neck problem in artificial intelligence. The wide variety of information for a complex spacecraft system further causes the knowledge acquisition problem even more difficult. An approach has been suggested by correlating the diagnosis knowledge acquisition with the work 'Failure Modes and Effect Analysis' (FMEA).[9] The architecture of the diagnostic system based on Fault Tree Modes are built upon a hierarchiclly decomposed functional model that determines 'failure' through abnormal component behavior. The system is based on the failure cause identification and has been enhanced in this implementation by replacing the knowledge base of 'if-then' rules with the 'object-oriented' faultm tree representation. This allows the system to perform its task much faster and facilitates dynamic updating of the knowledge base. The diagnostic system based on fault tree models makes the knowledge acquisition problem more easier. The diagnostic technique is not domain specific, it hase a general meaning.

5. The Prospects of intelligent Failure Diagnosis for a Spacecraft

The failure diagnodid is an urgent mission for a spacecraft, but it is a very complicated and difficult work. It is still under development and there is a long way to be perfected. Below is the tendency of its further development:

(1) The autonomy of on-board diagnosis will become an important tendency of development, so that the automation and robustness of diagnosis will attract the attention of research .

(2) The multiple faults will exist in a system simultaneously, and these faults may be coupled that increases the difficulty of diagnosis. The technique of diagnosis of multiple faults is a further research topic .

(3) In the design phase of a spacecraft any expected fault that may occur probably is considered and any possible reconfiguration is performed as far as possible , but unexpected fault is still unavoidable. It is said that when the spacecraft is in flight, usually the expected faults do not occur, and the occurred faults are not expected. The unexpected faults of course can not be diagnosed by rules. It has to turn to model-based diagnosis. The diagnosis of unexpected faults is a very difficult technique and is a further research topic .

(4) The most of the existing diagnostic system are only limited to the diagnosis of a subsystem or for partial functions. Attentions have to be paid to the development of whole spacecraft system.

(5) The reliability of diagnstic system itself is very important. The reliability of hardware and that of software should be improved meticulously, and the diagnosis of sensors and actuators themselves are tasks of first priority.

(6) The core of research is to raise and rich the theory and practise of the

diagnostic technique such as the diagnostic modeling, the methods of knowledge representation and reasoning, the diagnosis of inexact facts and rules with uncertainty, the reliability, robustness and the ability of fault tolerence of the hardware and software themselves, and so on.

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