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Research on Fault Diagnosis Technique of Spacecraft Payload

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Abstract. This paper elaborates the fault classification and different fault processing methods of spacecraft payload in orbit. The advantages and disadvantages of diagnostic method based on knowledge are analyzed. According to monitoring requirements on orbit management of spacecraft, a hybrid diagnosis model based on the combination of fault tree and case based reasoning is proposed, and the constructing approach of diagnostic knowledge and the reasoning process are dealt with. In the end, the experimental result verifies the effectiveness of the proposed method.

Introduction

With the rapid development of China's aerospace industry, a variety of spacecraft carrying different types of loads works on orbit, and plays an important role in the meteorological environment monitoring, land resources survey and other aspects. Once the failure of the spacecraft payload occurs, it will cause huge losses[1]. So it is very necessary to accurately discover the fault in the operation process in time, which lays the foundation for the timely troubleshooting.

Fault Classification of Spacecraft

The monitoring to the working status of the spacecraft in orbit is mainly divided into two ways: remote sensing data and telemetry data. Remote sensing data is the purpose of a spacecraft payload, the analysis of the data can partly find faults of payload. The telemetry data directly reflects the working status of the system. So the telemetry data is important input data to monitor the working status of the spacecraft.

From the angle of the telemetry data, the spacecraft fault can be categorized under the following 3 headings: single point fault, combined fault and temporal fault. Single point fault is refers to the fault which can be determined by the judging of a single telemetry parameter without other auxiliary information. Combined fault means to the fault which needs the combination judgment from multiple logical relationship of telemetry parameter. This type of fault is very complex and generally needs the consultation of experts in the field. Temporal fault is the fault which needs the comprehensive judgment of the telemetry parameters which have both logic relationship and time sequence. This kind of fault is more complex and the judgment should be deduced by combining with changes of telemetry parameter.

Fault Diagnosis Method based on Knowledge

The fault diagnosis method based on the knowledge integrates the expert experience and artificial intelligence technology. The expert experience is abstracted into the diagnosis knowledge. The automatic diagnosis of complex fault is realized through the software developing. This kind of diagnosis method does not need the complex model analysis, but has high diagnosis efficiency and widespread application[2] .

Diagnosis Method based on Rule Reasoning

Diagnosis method based on rule reasoning is also known as production method. In the method, the summary of expert experience for the fault diagnosis is abstracted to processing rules.

The advantage of this method is that the expression of knowledge is intuitive, easy to understand and interpret. The experience of experts in the field can be conveniently transformed to knowledge expression, and it does not readily make mistakes in the processing of knowledge translation.

Because the expression of knowledge is relatively simple and the requirement of the data storage space is not very high, diagnosis method based on rule reasoning facilitates to develop software system. But the method does not have adaptive ability and self-learning ability. In case of no corresponding rules in the library, a diagnosis error or failure will arise. The method is unable to apply in the field lack of experience of knowledge.

Diagnosis Method based on Fault Tree

Fault tree represents the logical relationship of the components in the system. According to the system architecture and function relationship, generally the most undesirable fault in the system is as the top event. The layer decomposition method is used to the system till the bottom event.

The advantage of this diagnosis method is that the logic relationship among complex problems can be clearly expressed and the diagnosis efficiency is improved. It is convenient to dynamically modifying the knowledge base and the diagnostic technique is domain independent, as long as the corresponding fault tree is given. However the diagnosis results of the method are heavily dependent on the information completeness of fault trees. Furthermore the method cannot diagnose the unpredictable system faults.

Case based Reasoning Diagnostic Methods

The core of case-based reasoning (CBR) method is to obtain scheme of the current problem through searching management experience of approximate cases in case knowledge base.

CBR diagnosis method has better adaptive ability and is an incremental method. The method is able to continuously update knowledge base and has a strong learning ability. So it overcomes bottleneck of the traditional diagnostic methods in knowledge acquisition. When the knowledge base is too large, the case search speed will be slow and the processing scheme may not be the best one. In addition, the method needs an accumulation of diagnostic cases.

Fault Diagnosis Method based on Multi-information Fusion

The method is refers to get a comprehensive analysis of the status information collected by a variety of ways, and ultimately obtain a comprehensive diagnosis. The diagnosis method can effectively improve the reliability and accuracy of the fault diagnosis results. Meanwhile it also has the disadvantages such as the influence of human factors, the difficulty to determine the degree of fault, and so on.

Fault Diagnosis Model for Payload in Orbit

For in orbit management of the spacecraft payload, the working states should be seized quickly and accurately and applied to estimate the consequences of failure so that further damages are avoided.

Combining with the development of artificial intelligence and computer technology, the fault diagnosis of payload in orbit[3] should be processed based on fault classification.

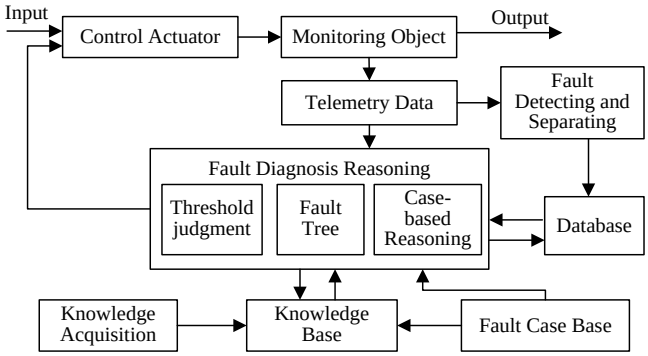

Figure 1 Structure of fault diagnosis based on hybrid reasoning

For a single point fault, the threshold judgment is used. For combined fault and temporal fault, the judgment process mostly similarities to the fault tree structure. Firstly the fault diagnosis method based on fault tree is applied to diagnose the fault. To avoid the insufficiency of fault tree, then case-based reasoning method is used as a supplement. The above mentioned approach conforms to the actual situation. The fault trees and diagnosis cases are derived from experts or experience knowledge. This model offers the reasoning process and describes the relationship between cause and effect. So the user can comprehend the abnormal degree and related components. The model can effectively combine the advantages of two methods of fault diagnosis to have the ability of rapid, efficient and comprehensive of fault diagnosis. The fault diagnosis model based on fault tree and case based reasoning is presented in Fig. 1.

Constructing Diagnosis Knowledge

In this hybrid diagnosis model, two kinds of fault diagnosis knowledge are required: one is the knowledge of fault tree diagnosis, and the other is the knowledge of fault case diagnosis. The construction method of the two kinds of diagnosis knowledge is introduced in detail below.

1) Constructing Fault Tree Diagnosis Knowledge

Fault tree is a logical structure that indicates the system fault event and the fault event of its subsystems or components.

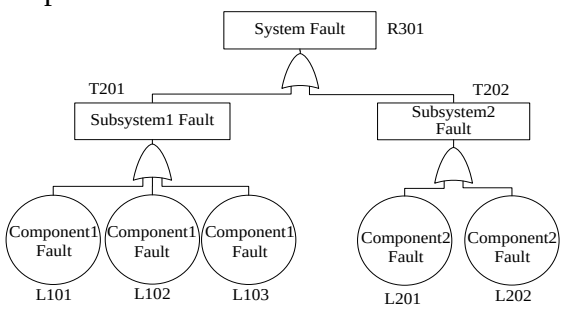

Figure 2 Example of fault tree

As shown in Fig. 2, the system fault (top event) is R301. T201 and T202(midst event) are subsystem faults. When one event in T201 and T202 occurs, a system fault is raised. T201 is caused by one of component fault (bottom event) L101, L102 and L103, and T202 is by one in L201 and L202.

It can be seen that the fault tree diagnosis knowledge is hierarchical. In the paper the framework is introduced as the basic representation of knowledge, and each frame structure corresponds to a node of the fault tree.

Each slot in the frame respectively represents the alarm information of the excitation node, the corresponding sub-frame number and the judgment rule. Frame knowledge structure is as shown in Fig. 3.

The fault tree in Fig. 2 will be converted to frame knowledge representation, as shown in Fig. 4.

Framework Number: The unique number that identifies the framework
Framework Content: Description of the framework
Framework Type: Identifies the type of the node framework
0：Root node, that is, the main framework
1：Intermediate nodes, that is, the sub framewok
Emergency treatment: Disposal method for this fault
When the framework type is 0, effective
Alarm Slot: Measuring point information which stimulates the node
Time Slot: Exciting moment of measuring point information, sEquential diagnostic knowledge. If no, fill null
Sub-framework slot: Indicating framework number corresponding to measuring point information. If no, fill null
Rule Slot: Production rule extracted from logic relation among fault tree nodes, denote as IF-THEN format

Figure 3 Structure of framework knowledge

Framework number: R301
Framework Content: System fault
FrameWork Type: 0
Emergency Measures：Immediately notify the satellite, and cancel the circle receiving plan
Alarm Slot: T201, T202
Time Slot: null, null
Sub-Framework Slot: T201, T202
Rule Slot: IF T201 THEN R301
IF T202 THEN R301

Framework number: T201
Framework Content: Subsystem 1 fault
Framework Type: 1
Alarm Slot: L101, L102, L103
Time Slot: T0-600s, T0-250s, T0-15s
Sub-Framework Slot: null, null, null
Rule Slot: IF L101 THEN T201
IF L102 THEN T201
IF L103 THEN T201

Framework number: T202
Framework Content: Subsystem 2 fault
Framework Type: 1
Alarm Slot: L201, L202
Time Slot: T0-60s, T0
Sub-Framework Slot: null, null
Rule Slot: IF L201 THEN T202
IF L202 THEN T202

Figure 4 Framework of fault tree

2) Constructing Fault Case Diagnosis Knowledge

Generally speaking, the case contains two parts of the problem and its solution, and has specific content in different domain. The spacecraft payload possesses a complex composition and its working process relates with multiple subsystems. By analysis of a large number of spacecraft faults events and according to the flow of fault occurrence, the payload event fault model is established as shown in Fig. 5 in this paper.

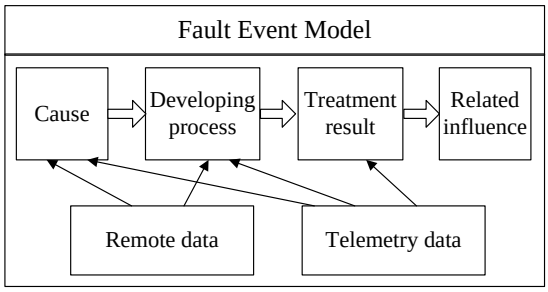

Figure 5 Fault event model

Thereinto, the cause indicates the fundamental reasons that lead to the fault. The cause contains specific fault time and fault characteristic. Processing result includes measures to deal with the fault, and whether the treatment is a success. Related influence is refers to the effect caused by the fault on mission and subsequent usage of the spacecraft.

A case of spacecraft payload fault is expressed with a quintuple: C = < D, F, S, M, E >, which D = {d1, d2, … , dn} for describing basic characteristics of the fault, including satellite, subsystem, fault number, fault name and fault type. F = {f1, f2, … , fn}, it is the other subset of C, which describes telemetry data corresponding to the payload faults. S indicates the diagnosis result corresponding to the fault, including measures to solve the problem, and causes. The M represents the effect caused by the fault. The E expresses the supplementary information of fault case, including remote data and telemetry data. Hence the structure of the fault case of the spacecraft payload can be defined as shown in Fig. 6:

```
Class FaultCase
{
    FCaseName;          // The name of fault case
    FCaseBH;            // The number of fault case
    FCaseBasicInfo;     // Essential information of fault case
    FSignSet;           // Fault symptom set, including qualitative and
                           quantitative symptom
    FaultReason;        // Cause to the fault
    FautlSolution;      // Treatment to the fault
    FaultInfluence;     // Influence caused by the fault
    RemoteData;         // Fault related remote data
    TelemetryData;      // Fault related telemetry data
    CaseSimilarity;     // Similarity of fault case
    CaseStorage();      // Storage function of fault case
    CaseMatch();        // Similarity matching function of fault case
    MatchTimes;         // Matching times
  }
```

Figure 6 Structure of the fault case

Hybrid Reasoning Processes

According to the above analysis, when the spacecraft telemetry data is received, firstly fault tree based method is adopted to payload states. If the corresponding fault tree is searched with no success in the library, the diagnostic methods based on case reasoning should be used. If two methods have not been successful, then the manual processing is transferred. The process of hybrid reasoning is shown in Fig. 7. Specific steps are described as follows:

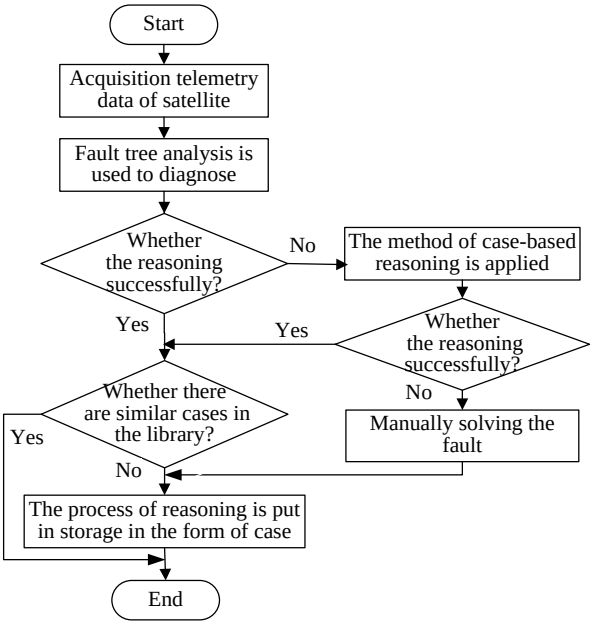

Figure 7 Diagnostic reasoning flow

- The first is to obtain the processing results of satellite telemetry data, while error codes in telemetry data is eliminated to reduce misjudgment.
- Entering fault tree based reasoning process. According to measured satellite remote sensing values, combined ground payload control plan, the diagnostic reasoning process based on fault tree is adopted. If there are matched fault tree in fault tree knowledge base and is able to draw the fault conclusion, the diagnosis process is finished. Otherwise, turn the next step.
- Entering case reasoning process. The diagnosis method searches for similar historical cases in the case knowledge base. If the match is successful, and there is no similar case in case base, the reasoning process is expressed as a case and stored to the fault case base in order to subsequent use. The diagnosis process is finished. Otherwise, turn the next step.
- If above approach is unable to give result, then turn to manual processing. After the experts successfully solve the fault, the information such as fault phenomenon, fault causes and solving measures are stored in the knowledge base in the form of case, in order to prepare for the subsequent use.

The following will provide its application, experimental analysis and conclusion in the field. In order to verify the applicability and effectiveness of the reasoning model proposed above, 26 faults occurred in 7 satellites within 1 years are chosen to analyze. The fault tree based method, case based method and the hybrid reasoning method of fault tree and case based are respectively applied to these faults. The statistical results of diagnostic process are as shown in Fig. 8.

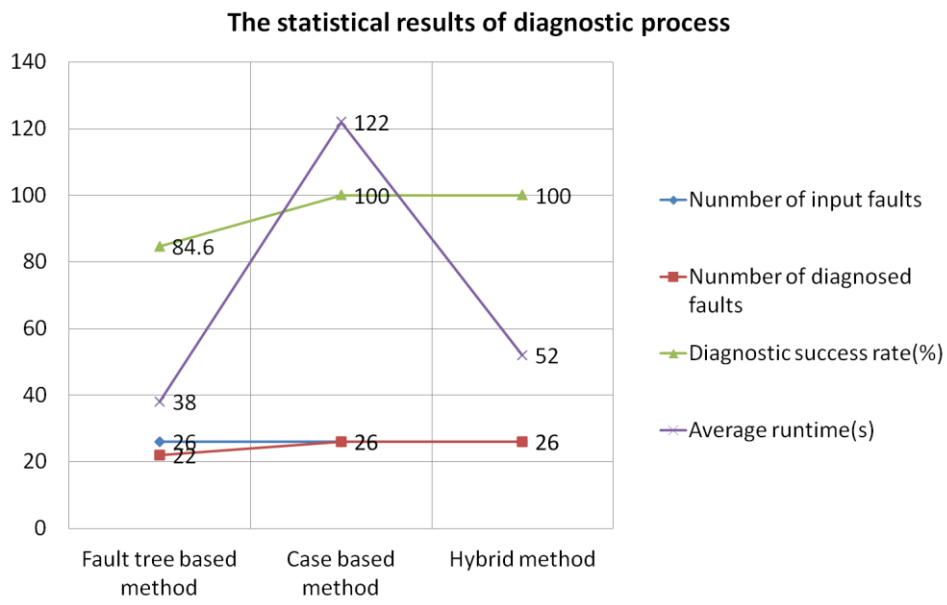

Figure 8 Statistical results of diagnostic process

From the statistical results in Fig 8, the conclusions are as followings:

The fault tree based method makes the fault diagnosis simple and direct owing to the clear knowledge structure. The average runtime of this method is the shortest one among 3 methods. But if there are no corresponding fault trees, the diagnosis process will collapsed.

The case based method is able to reach a higher diagnostic success rate and needless of precise diagnosis knowledge in the promise of a full and comprehensive historical cases. Meanwhile because of the complicated process of retrieval and matching, the diagnosis rate of this method is slow and the average runtime is the longest one among 3 methods.

The diagnosis method proposed in the paper adopts reasoning model which is mainly based on the fault tree and supplemented by case. When the model is employed for diagnosis, the fault tree method is firstly used. Once the method is unable to give the result, supplementary diagnosis is made by case based method. This diagnosis method promotes both the rapidity and the successive rate of fault diagnosis.

Concluding Remark

Payload is the key part to the mission of the spacecraft in orbit. It is an important task in orbit management to ensure its safe and stable operation. The premise to complete the work is the efficient fault diagnosis.

In this paper a fault diagnosis model based on combination of fault tree and case-based reasoning is proposed. The knowledge and rules are expressed in the form of a tree structure which is intuitive and easy to understand. To avoid the inability to diagnose the fault due to incompleteness of fault tree, the diagnostic method based on case is combined with. Case based reasoning method can provide approximate solution on account of historical case matching for the fault with no explicit knowledge. Experiment shows that the hybrid diagnosis model can give full play to the advantages of each reasoning method and achieve a better fault diagnosis effect.

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