Research on Intelligent Flight Test Monitoring Technology Based on Expert System

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Abstract. The current manual-based traditional flight test monitoring technology can no longer fulfill the requirements of high integration, system complexity and technological advancement of new aircraft. In addition, the existing flight monitoring systems are mostly single-point, single-system applications, including ground-assisted systems such as meteorology, radar, and response system. It is easy to cause problems such as data islands, which is not conducive to data sharing and comprehensive evaluation and analysis. This paper proposes a new method for analyzing and mining existing test data based on expert system technology to build a flight test expert system library. A new real-time monitoring system is designed that can meet the real-time processing and integration of multi-source data, comprehensive evaluation and analysis, intelligent warning and assistant decision-making. This system expands the function and intelligence of the existing system, and further improves the quality, safety and efficiency of the flight test monitoring system.

1. Introduction
The real-time monitoring technology of flight test has always been one of the key technologies in the field of flight test in China and abroad. It is not only important for the exploration of new machine performance boundary and the ultimate challenge security guarantee, but also can quickly judge flight through real-time processing and analysis of flight data. However, with the continuous development of new aviation technology, the traditional flight test real-time monitoring technology has gradually failed to meet the needs of the new model “high complexity, large data volume, long flight time”. However, the limited ability of human beings (slow reaction speed, fatigue, unstable reliability) has become a potential hidden danger of flight test safety monitoring. In addition to the hierarchical alarm function, the parameter correlation mainly depends on the professional knowledge of flight test engineers. Monitoring based on aircraft platform data, relatively single, lack of comprehensive analysis and evaluation. As a result of a modern aviation study, "the cause of equipment failure is no longer the main cause of flight accidents. The biggest threat to aviation safety today is human unsafety."

The expert system is an intelligent program system with a large amount of expert knowledge in related fields. It is an important research field of artificial intelligence and a knowledge-based heuristic reasoning system. It is currently used in meteorology, geodesy, medicine and other fields. The advantages are fast calculation, good consistency of results, more professional and liberating manpower. Therefore, it is of great significance to carry out research on intelligent monitoring technology based on flight test expert system in the field of real-time monitoring of flight test.
2. System architecture design
To be used for real-time monitoring, you must ensure that the data is monitored in real time. This research involves the expert knowledge base and the frequent operation of the comprehensive database. The regular database operation response is slow (time is in the second order) can not meet the requirements of real-time. The main ways of solving the current technology are: shared memory technology and in-memory database technology, but sharing Memory technology can only meet the system with relatively small amount of data, so the overall architecture of the paper adopts the "storm+memory database (MMDB)" approach. Storm is the current mainstream real-time big data processing system with the advantages of distributed, scalable, and fault-tolerant. The block diagram of the system is shown in Figure 1. The system is based on a private cloud communication platform and has a wide-area data interconnection and sharing function, and is mainly composed of a communication platform layer, a data layer, a processing layer, and an application layer.[1]

3. Flight test expert system design
The expert system is an intelligent program system with a large amount of expert knowledge in related fields. It is based on artificial intelligence technology and simulates the thinking mode of human experts to make problem reasoning and decision making, especially for highly complex systems. In view of the high risk and high complexity of flight test, the safety monitoring technology based on the flight test expert system is to improve the quality and efficiency of flight test safety monitoring and reduce the false alarm rate. The structure of the flight test expert system is shown in Figure 2. It consists of knowledge base, inference engine, interpreter, comprehensive database, knowledge acquisition, human-machine interface, and autonomous learning drive. The core is knowledge base construction, knowledge representation, and inference algorithm design. The autonomous learning module is the basis for the development of the future flight test expert system. It is a function expansion module that directly converts the original data, security model and semantics into rules based on certain learning algorithms and realizes advanced intelligence[2]
3.1. Knowledge acquisition
For the flight test safety monitoring, knowledge acquisition is a process of extracting expert knowledge base elements from many abnormal data, voice and video images. It can be divided into manual and automatic modes. The flow chart is shown in Figure 3. The main methods are based on neural network, machine learning, etc. Considering the maturity of knowledge acquisition algorithm and flight test safety, this paper adopts the method of artificial knowledge acquisition, and builds the test flight safety monitoring fault tree model by flight test experts and flight test engineers to acquire knowledge. The advantage is the authority and reliability of knowledge. The difficulty is how the model map is transformed into rules and how the information of each element is stored in the knowledge base. Taking the simpler dual-engine aircraft residual fuel safety as an example, the safety model diagram is shown in Figure 4.[3]
Is the remaining oil quantity safe?

Figure 4 Remaining oil quantity fault tree safety model diagram

3.2. Knowledge base design
The knowledge base is an extremely important part of the expert system. The quality of the knowledge base directly affects the quality of the expert system. The main function of the knowledge base is the rule engine and rule management. It is a collection of test flight security monitoring models, including description information, calculation rules, thresholds, and so on. Any rule contains two parts, conditions and conclusions. The conclusion is unique in most cases, but there will be more than one condition. Combined with the characteristics of flight test security monitoring, the middle rule of the knowledge base contains multiple conditions, and the conditions are related to (coincidence), and there is only one conclusion. Considering the frequent operation of the knowledge base by the system, in order to improve the real-time performance of the security monitoring application, this paper uses the MEMORY storage engine of the in-memory database MySQL. The following is the design of several major tables in the knowledge base.[4]

Table 1 Fault Tree Node Location Information Table

| Field    | Data Type | Description                  |
|----------|-----------|------------------------------|
| NodePosID| CHAR      | Node location number         |
| FactID   | CHAR      | Fact code                    |
| ParentNodePosID | CHAR   | Parent node number          |
| NodeChildNum | INT     | Number of child nodes       |
| NodeChildNumType | INT    | Node type                   |
| MatchDegree | Text type | Node similarity weight     |

Table 2 Rule table

| Field    | Data Type | Description                        |
|----------|-----------|-----------------------------------|
| RuleID   | CHAR      | RuleID                            |
| PreFactList | VARCHAR | Fault condition code chain       |
| ConclusionID | VARCHAR | Rule conclusion number           |
| ReasonLevel | INT      | Conclusion The number of nodes in the fault tree |
| MatchDegree | Text type | Node similarity weight          |

Table 3 Reasoning Dynamic Table

| Field    | Data Type | Description                  |
|----------|-----------|------------------------------|
| RuleID   | CHAR      | Rule number                  |
| FactID   | CHAR      | Symptom number               |
| ReasonProcess | Long    | Reasoning step               |
| ReasonOrder | Int      | Reasoning step               |
| RuleOrder | Double    | suitability                  |
| FEATURESETID | VARCHAR | Symptom set number          |

3.3. Inference engine design
The inference engine is the core part of the expert system. The function is to find the best problem solving method based on the problem, fact and control strategy, which is divided into forward reasoning and reverse reasoning. Flight test safety monitoring is based on data and phenomenon facts, so forward
reasoning based on fault tree model can also be called data-driven reasoning. In the design, the similarity weight attribute is set to the knowledge item according to the security model, which improves the speed of inference calculation. The reasoning process is briefly described as follows:

1) Send relevant real-time data to a comprehensive database (DB) for a security model;
2) Check whether the data feature value in the DB already contains the solution of the problem, and if so, return the result to the end of the solution and push it out; otherwise, execute the next step;
3) According to the DB comparison results, check whether there is a matchable knowledge in the knowledge base (KB), if any, go to 4), otherwise turn 6);
4) Select all available knowledge in the KB to form a usable knowledge set (KS);
5) If KS is not empty, a knowledge is selected according to the similarity weight and preference strategy, and the generated new process quantity is stored in the DB, and then transferred to 2) iterative reasoning process; if KS is empty, then Failed to exit;
6) Reasoning fails to exit.

Setting the similarity weight attribute and the preference strategy is mainly to solve the optimal choice and eliminate the conflict problem. In addition, it is necessary to design a matching algorithm for data and knowledge, a search algorithm for knowledge in the knowledge base, and the like.[5]

4. Application of Intelligent Security Monitoring Technology Based on Flight Test Expert System

4.1. Intelligent warning and assistant decision making technology
Intelligent warning and auxiliary decision-making technology is to judge the critical state and change trend of important parameters such as aircraft platform, power plant and avionics system that affect aircraft safety, and express it in various forms such as warning lights and voice. On the basis of fault analysis and positioning, the emergency fault handling procedures and contents are displayed accurately and concisely on the monitoring software interface for the important fault states that endanger the safety of the aircraft or the flight test subjects, so as to improve the quality of safety monitoring and the success rate of special handling. Based on computer software and multimedia technology, the technology implements dangerous trend warning, fault grading and positioning display, multi-level alarm voice prompt and knowledge-based assistant decision-making function based on conventional security monitoring. The traditional practice of this technology is based on some key parameter values and the professional knowledge and experience of flight test engineers. The false alarm rate is high. With the construction of the flight test expert system, the test flight safety model can effectively reduce human error and improve the accuracy of safety warning. The success rate of degree and special treatment will improve the intelligence level of the system. The structure of the intelligent alarm early warning and auxiliary decision-making technology system is shown in Figure 5.[6]
The technology mainly includes the following key technologies:

1) Grading fault early warning and disposal decision-making technology: Based on the test flight expert system, the new alarm monitoring mechanism combining grading alarm and comprehensive alarm is used to refer to the multi-level alarm mode of the aircraft system to realize the comprehensive monitoring of the three-level fault alarms of prompts, warnings and alarms. In advance, judge the development trend of the fault to obtain more reaction time for the special situation; verify the mutual alarm with the comprehensive alarm, and quickly locate the specific fault location of the subsystem after confirming the alarm.[7]

2) TTS-based voice alarm technology: Text to Speech (TTS) refers to text synthesis to speech synthesis. This technology uses Microsoft's Microsoft Speech SDK speech engine software to convert any text information into standard in real time. Smooth voice playback. Breaking through the traditional mode of seeing the problem of visual discovery, the mode of joint action of vision and sound is realized, which effectively improves the accuracy and timeliness of fault finding.

4.2. Quasi-real-time analysis and evaluation techniques

The so-called quasi-real-time evaluation and analysis technology is relative to real-time monitoring and analysis technology and post-mortem data processing and analysis technology. The biggest advantage of post-processing technology is the strong processing capability and comprehensive information, which can handle more complicated analytical calculations, such as high-frequency vibration analysis and flight test subject evaluation. The biggest advantage of real-time monitoring and analysis technology is strong real-time performance and data analysis results lag. The action implementation time does not exceed 150 milliseconds, and can be detected and disposed of in time for various sudden faults. Quasi-real-time evaluation and analysis technology combines the advantages of the above two technologies, and advances some important complex calculation and analysis functions that can only be processed afterwards to the real-time processing and analysis stage. It is an extension of real-time monitoring technology. The improvement of processing technology is an innovative data processing technology. Taking the flight test evaluation as an example, the system core processing software flow chart is shown in Figure 6. The main performance indicators of the technology are as follows:

Analyze and evaluate technical indicators for routine test flight subjects such as performance, quality, and flight control:

1) Analysis processing time: less than 2 minutes;
2) Processing parameter rate: 1~32bps is optional.

Load analysis calculation and evaluation technical indicators:
1) Analysis processing time: less than 2 minutes;
2) Processing parameter rate: 512bps, 1024bps.

Figure 6 Quasi-real-time analysis system core processing software flow chart

The technology mainly includes the following key technologies: Wild point culling algorithm: In the flight test, external interference and accidental jitter of the instrument may cause the measurement result to have a very unreasonable hop, called the wild point. Therefore, it is necessary to remove the wild spots before the quasi-real-time evaluation of the flight test data, otherwise the correctness of the
evaluation results will be affected. In this system, the seventh-order second-order formula is used to judge and eliminate the wild value. The seventh-order equation is as follows:

$$\hat{y}_1 = (32y_1 + 3y_2 + 3y_3 + 4y_4 + 6y_5 - 3y_6 + 5y_7) / 42$$  \(1\)

$$\hat{y}_2 = (5y_1 + 4y_2 + 3y_3 + 2y_4 + 4y_5 + 5y_7) / 14$$  \(2\)

$$\hat{y}_3 = (y_1 + 3y_2 + 4y_3 + 4y_4 + 3y_5 + 6y_6 - 2y_7) / 14$$  \(3\)

$$\hat{y}_4 = (y_1 + 3y_2 + 6y_3 + 7y_4 + 6y_5 + 3y_6 - 2y_7) / 21$$  \(4\)

$$\hat{y}_5 = (-2y_1 + y_2 + 3y_3 + 4y_4 + 5y_5 + 3y_6 + 1y_7) / 14$$  \(5\)

$$\hat{y}_6 = (y_1 + y_2 + 2y_3 + 4y_4 + 5y_5 + 4y_6 + 5y_7) / 14$$  \(6\)

$$\hat{y}_7 = (y_{i-6} - 3y_{i-5} - 6y_{i-4} - 7y_{i-3} - 4y_{i-2} + 15y_{i-1} + 32y_i) / 42$$  \(7\)

(i=7,8,9,...,N)

Where i=7,8,9,...,N, \(y_i\) is the original test data, and \(\hat{y}_i\) is the difference after the data. First check that the first six points are normal points, and use this formula to calculate chronological order \(\hat{y}_i\) and \(v_i = y_i - \hat{y}_i\). For wild spots, \(v_i\) much larger than normal. Experience has shown that those who meet the following formula are wild spots:

$$|v_i - \hat{y}_i| > 2.2 \sqrt{\sum_{j=1}^{6} (y_j - \hat{y}_j)^2 / 6} = E$$  \(8\)

Usually, the values of consecutive hops in real-time data are relatively close, and continuous hops can be proposed by the following formula. When k is a wild value, the point that satisfies the following formula is also a wild value:

$$|v_{i+1} - v_i| < E \quad (i=1,2,3,4,...,m)$$  \(9\)

In the test data, there are rarely more than 4 consecutive hops, so take m=3 to avoid using the step signal as a wild point culling.

5. Conclusion

As the new type of aircraft system becomes more and more complex, the problems to be solved by the flight test expert system will be gradually multi-sourced, which is not conducive to the quality and efficiency of expert system problem reasoning. It can be divided into several sub-expert systems according to different professional fields of test flight to form large multi-expert collaboration system.

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