Research on the fault diagnosis and self-healing technology of unattended Antarctic telescope

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ABSTRACT

This paper presents an expert system fault diagnosis and seamless self-healing scheme based on artificial intelligence, which is used for the astronomical telescope drive system. For the faults that have already occurred, the expert system inference mechanism can be used to realize quick localization of failure, and we can use the expert solution in the knowledge base to run the self-healing decision until the failure is resolved. For the failure the knowledge base doesn't have, we can use human-machine interface to achieve real-time update of the knowledge base. For the faults that didn't occurred, the trained adaptive BP neural network is used to fit the parameters of the telescope running status, to monitor the running status of the telescope in real time and to realize the fault warning of the telescope operation. Fault diagnosis and seamless self-healing technology is one of the key technologies to realize intelligent, its research is of great significance.

Keywords: Astronomical telescope, Fault diagnosis, Self-healing, Intelligent, Expert system

1. INTRODUCTION

1.1 Background and significance

The Antarctic telescope makes full use of the advantageous condition for astronomical observations at the Dome A, but the Antarctic is a double-edged sword. There are great challenges which the telescope faces behind the nearly perfect observation condition. Antarctic Kunlun Station at Dome A is an unmanned station in winter. The Antarctic telescope needs long-term work on the unattended Dome A. The failure of the telescope will result in missing the best time for astronomical observations, losing of important astronomical data and other serious consequences. Therefore, it is urgent to study the fault diagnosis and intelligent self-healing strategy of the Antarctic telescope control system.

Chinese Antarctic Survey Telescope AST3-1 and AST3-2 have respectively installed in the Antarctic Kunlun station in 2012 and 2014, and the developing AST3-3 which will form the sky telescope array with the first two is planned to arrive to Kunlun in 2019. The 2.5-meter Kunlun Dark Universe Survey Telescope (KDUST)[1] and the 5-meter Terahertz Telescope (DATE5) have also been on the agenda[2]. The application of Fault diagnosis techniques to large-scale Antarctic telescope is still in its infancy. This study is of great significance for reducing the on-site maintenance time of Antarctic expeditions, reducing the cost of operation and maintenance and gaining valuable time for astronomical observations. NASA, for example, in the United States due to spend a lot of money for spacecraft system fault diagnosis and its health management technology research every year, the space shuttle flight risk was reduced by 50%, run budget reduces the one-third[3].

1.2 Research status and trends

Each science and technology developed country in the world attaches great importance to the development of astronomy. From ELT, EELT, and SKA to China's FAST, LAMOST and AST3, all indicate that the development of astronomical instruments will reach an unprecedented height.

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Australia Telescope (AT) analysis about 12000 monitoring data per minute, reports specific components in array and the health and stability of the signal path, the data is divided into categories used to match with a tag of the known failure modes, judge array fault. The 10 meters Antarctic telescope, installed in Amundsen Scott stands at the South Pole will record encoder position, motor current and fault information every 10 milliseconds, and timely notify the on-duty staff maintenance[4]. Yu-Xia Li of the Changchun Institute of Optics and Mechanics, Chinese Academy of Sciences and others have developed a set of fault diagnosis and detection systems for large telescopes based on LABVIEW. Through a standardized collection and storage module and the external different sensors, the system can realize real-time measurement, acquisition, storage, display and analysis of the position, speed, acceleration and tracking error of the large-scale telescope, also can realize on-line monitoring of voltage, current, temperature, humidity and other electrical and environmental conditions[5]. Others have designed a fault diagnosis system that detects and locates faults in time during an adaptive optical wave front processor based on a field programmable gate array (FPGA)[6]. M Nyberg et al. proposed a method to estimate the health status of normal component a suspected fault, or a confirmed fault condition. Based on the results of the test, the results of the minimum conflict were determined[7].

With the development of artificial intelligence technology, fault diagnosis should also be on the intelligent road [8]. The diagnostic method is no longer a single mode, but a combination of multiple diagnostic methods to promote and complement each other. Information, agility and intelligence are the trend of the research and development of remote intelligent fault diagnosis technology for complex equipment [9].

2. FAULT DIAGNOSIS AND SELF-HEALING EXPERT SYSTEM DESIGN OF ANTARCTIC TELESCOPE

The Antarctic telescope is a complex dynamic system of optical-mechanical-electrical system. The fault diagnosis and self-healing of the Antarctic telescope are studied by using fault tree diagnosis and expert system. Both of them take advantage of their advantages and avoid their disadvantages. In addition, the function of traditional expert system is extended to the category of self-healing while improving the efficiency of fault diagnosis.

2.1 Diagnosis and self-healing expert system composition

A rule-based, reasoning-centric expert system consists of six components: knowledge acquisition machine, system knowledge base, inference engine, integrated database, man-machine interface and interpreter. The expert system has features such as heuristic, transparent and flexibility. The fault diagnosis and self-healing expert system functions of the Antarctic telescope control system designed in this paper are more perfect, the system can not only locate the fault under the guidance of the expert system quickly, and infer the cause of the fault, but also can realize the self-healing function of the partial fault by sending self-healing instructions within the range of self-healing.

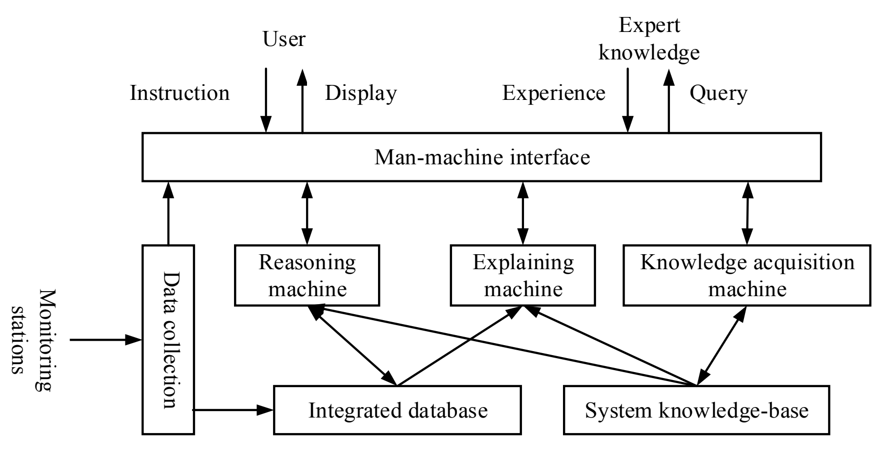


Figure 1. Expert system structure diagram

2.2 Establishment of knowledge base

The knowledge base in this article adopts a design method based on an associated database. This can make full use of the advantages of the database itself, and can be well integrated with the expert system. So it greatly improves the efficiency of the thrust and is convenient for the expansion and maintenance of the knowledge base of expert system.

When designing a database based on knowledge base, the existing expert knowledge is stored in four tables Fault, Phenomenon, Reason and Solution. Table Fault is mainly used to store failure mode, which has two fields FaultID and Fault which are used to store the fault number and fault mode name respectively. Table Phenomenon is mainly used to store the fault phenomenon. There are three fields in the table PhenomenonID, Phenomenon and FaultID, which are separately used to store the fault phenomena number and fault phenomenon description and serial number. Table Reason is mainly used to store the cause of the fault, there are four fields in the table ReasonID, Reason, Weight and PhenomenonID, which are separately used to store the fault cause number, description of the fault cause, the weight of the fault cause and fault symptom number. Table Solution is mainly used for store solutions, there are three fields in the table SolutionID, Solution, Weight and ReasonID, which are separately used to store the solution number, solution description, weighting for the solution, and failure cause number. The created data table and its structure are shown in the figure 2 below.

FaultID	nchar(10)	☐
Fault	nvarchar(50)	☑
		☐

PhenomenonID	nchar(10)	☐
Phenomenon	nvarchar(50)	☑
FaultID	nchar(10)	☑
		☐

ReasonID	nchar(10)	☐
Reason	nvarchar(50)	☑
Weight1	float	☑
PhenomenonID	nchar(10)	☑
		☐

SolutionID	nchar(10)	☐
Solution	nvarchar(50)	☑
Weight2	float	☑
ReasonID	nvarchar(50)	☑
		☐

Figure 2. Data tables and their data structures

Field of the four tables FaultID actually is used to store the fault mode index, according to the index value to realize the failure mode to the failure phenomenon, the derivation of the same field PhenomenonID index to the reason of the failure phenomena to failure, the derivation of field ReasonID index to realize the reason of the failure to the fault of the solution are derived. The Weight of the corresponding fault causes is stored in the field Weight in the data table of the fault cause, which is used to realize the intelligent analysis problem. The program can select the most likely situation according to the Weight. The weight is set by consulting expert opinion and summarizing experimental experience, which has certain credibility. Similarly, the field Weight2 in the solution data table is set in this manner. The establishment of this database also lays a foundation for the design of the reasoning machine below. The correlation diagram of the four data tables is shown in the figure 3 below.

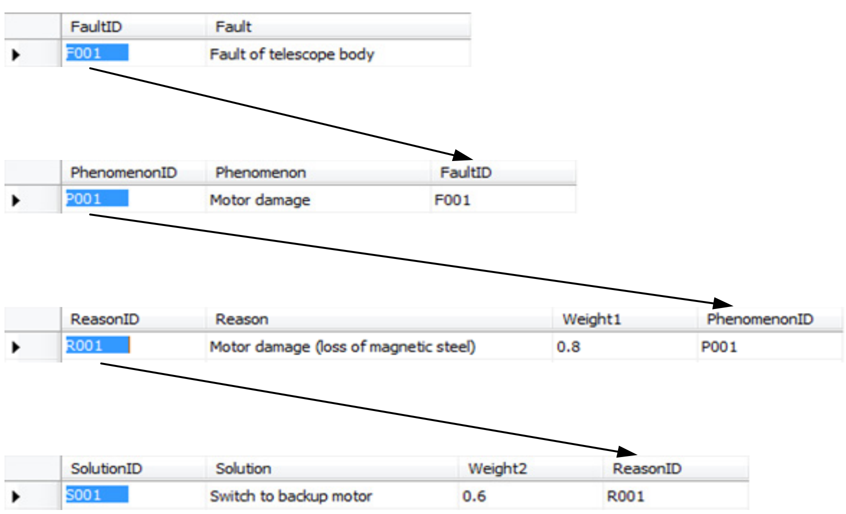


Figure 3. Correlation diagram between data tables

2.3 The realization of the inference engine

The reasoning machine is the core component of the expert system, and the realization of the reasoning algorithm embodies the intelligence of the expert system. The efficient inference mechanism can realize the fast localization of the fault and give the solution quickly. In the premise of realizing fault diagnosis, this paper adds self-healing function to expert system. After the expert system has given the corresponding solution, the system will automatically send the corresponding solution execution statement to prompt the executing agency to respond. This is the difference between the research and the traditional expert system.

In this article, the design of the inference engine combines the knowledge of relational database, according to the analysis of the previous section, through the index established between data tables, the cause of failures can be inferred from the failure phenomenon and then infers the corresponding solutions. The fault phenomenon is judged by the data of the corresponding monitoring points set by the telescope, and we will illustrate this by applying examples in the next part. If a fault in the expert system can be caused by a variety of reasons, the inference engine intelligently gives the most probable cause based on the weights set in advance in the data table. The reasoning of the Solution uses the same mechanism to infer the most probable solution and execute the corresponding self-healing instruction. If the fault is resolved the process ends and if the fault is not resolved, the next solution is executed. If all solutions do not resolve the fault, the expert system determines that it is not the cause, infers the second possible cause of the fault, and then executes the related solution until the fault is resolved. The following figure is the study's mixed reasoning process flow (figure 4) and fault diagnosis and self-healing flow (figure 5).

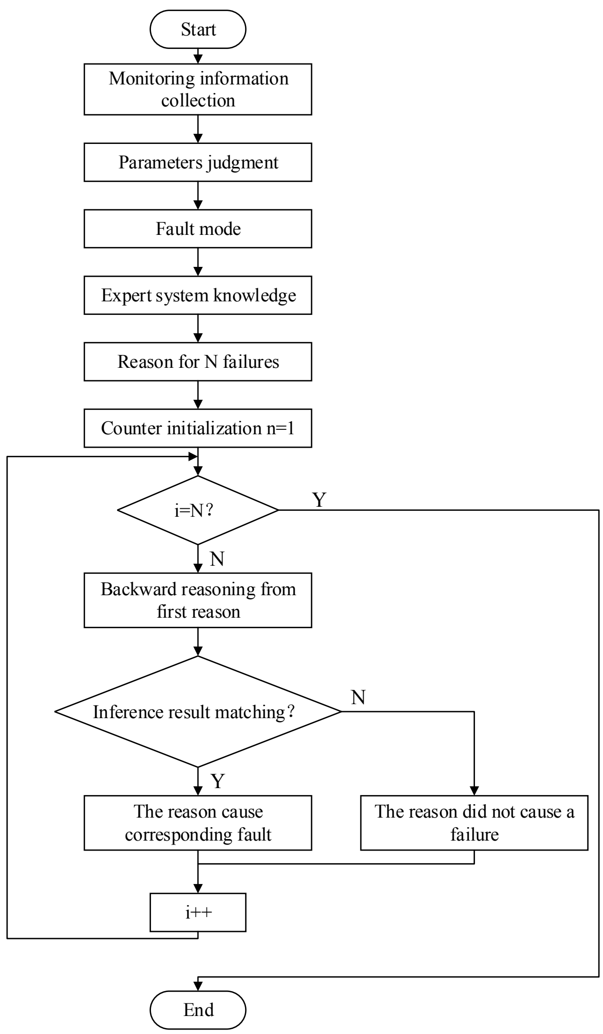


Figure 4. Hybrid inference flow chart

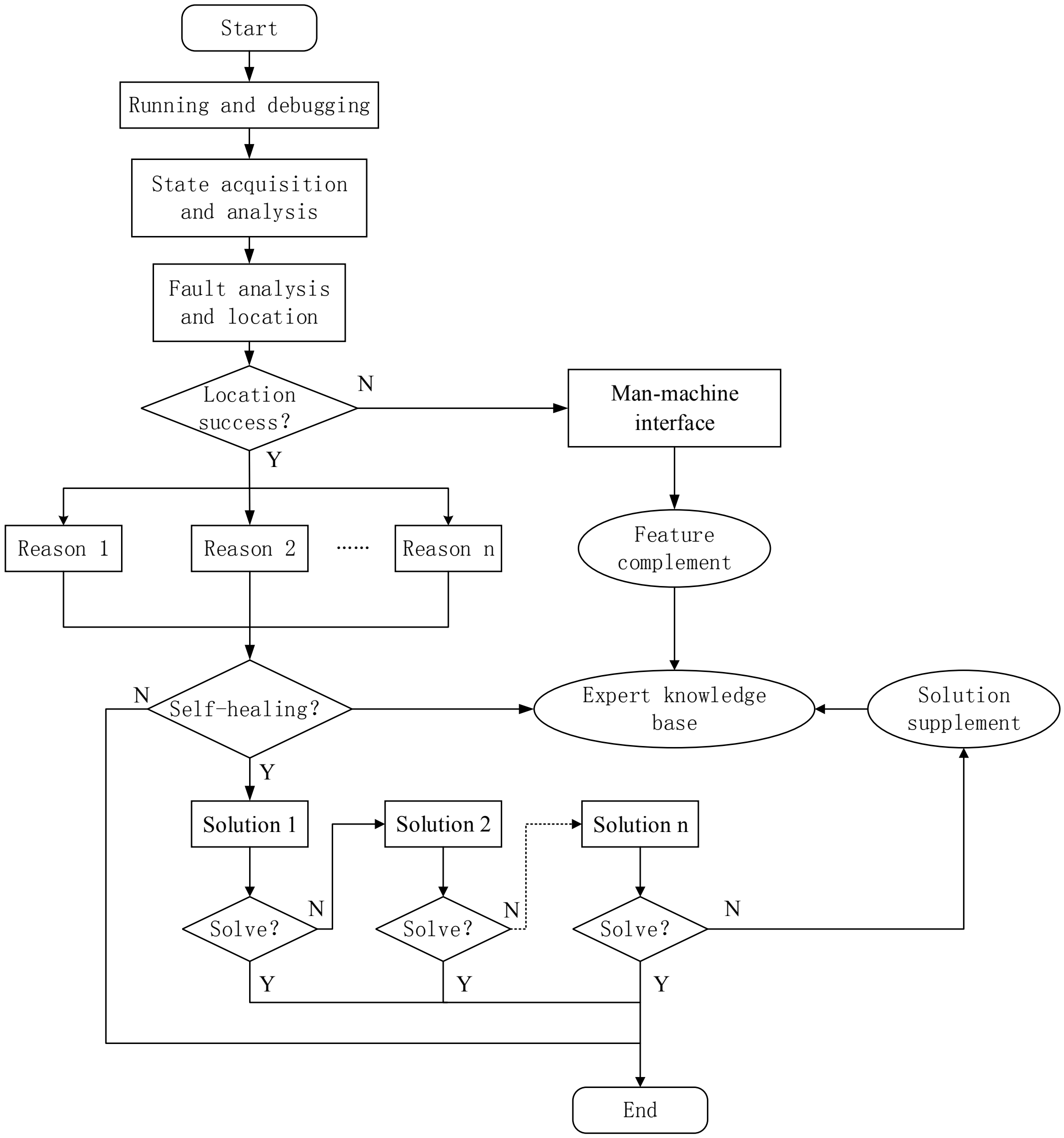


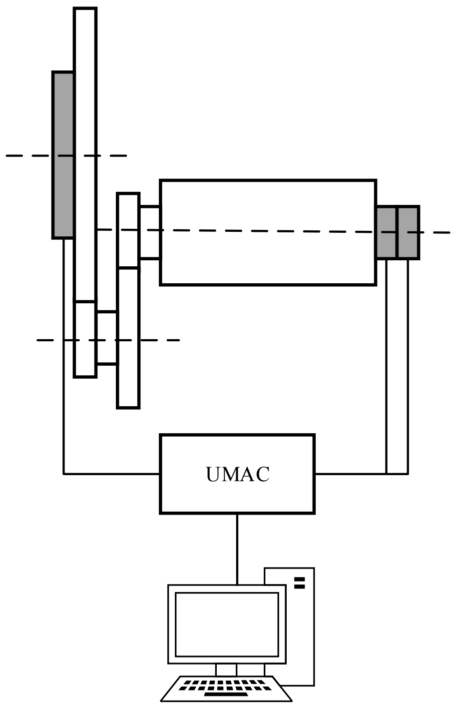
Figure 5. Diagnostic and self-healing flow chart

3. EXAMPLES OF APPLICATION

Due to the cost of direct drive motor, severe weather in the Kunlun Station and the shortage of power resources, the main shaft driving system of the large aperture telescope in the Kunlun Station usually adopts servo motor and gear transmission structure. Taking the Antarctic Survey Telescope AST3-3 as an example, the main shaft transmission system of this telescope adopts the double-motor multi-stage gear anti-backlash transmission structure.

The astronomical telescope is a high-precision device. The anti-backlash of the gear transmission structure affects the pointing and tracking accuracy of the telescope directly. Astronomical observation means a miss is as good as a mile. If the anti-backlash fails, the transmission angle between the input shaft and the output shaft of the transmission will be affected which will affect the pointing and tracking accuracy. The realization principle of the failure of the mechanical clearance of the device is shown in the figure 6.

The multi-axis motion controller reads the position information of the resolver and incremental encoder in real time, and the mathematical calculation can accurately determine the transmission angle ratio of the gear transmission system. If the transmission angle ratio of the telescope in the pointing and tracking state are the same, it means that the mechanical backlash of the gear transmission structure has no failure. The detection flow chart is shown in the figure 7.



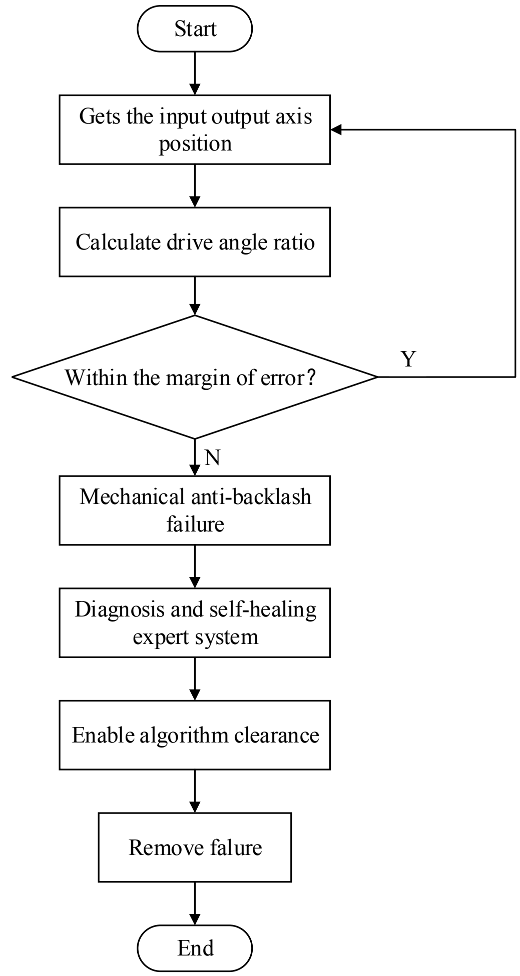


Figure 6 (Left). Principle diagram of mechanical clearance failure

Figure 7 (Right). Fault diagnosis and self-healing flow chart of mechanical clearance failure

4. CONCLUSION

In this paper, a fault diagnosis and self-healing expert system is established for Antarctica telescope, and its feasibility is verified. This study provides technical support for the telescope, and also the practical significance of this method is proved.

Compared with previous research in this field, this paper has the following innovations:

(1) For the first time, the fault diagnosis and intelligent self-healing technology was applied to the control system of Antarctica telescope, the conditions and tactics for fault diagnosis and seamless intelligence self-healing of the control system of the south Antarctica telescope were clarified and gave a method for building a self-healing system.

(2) This paper establishes an intelligent expert database for fault diagnosis of Antarctica telescope. The expert database is an open type. With the deepening of research, it is allowed to be expanded and corrected. The expert system is also suitable for fault diagnosis and self-healing of KDUST.

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