Research on Fault Diagnosis Training System Based on Virtual Space Launch Site

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Abstract. Aiming at the problem that the ground equipment system of space launch range is complex and it is difficult to implement real fault diagnosis training, this paper analyses the requirements of fault diagnosis training, puts forward a design scheme of fault diagnosis system based on virtual range, and expounds the basic workflow of virtual fault diagnosis training system. The fault tree and expert system are combined to complete the fault diagnosis training process design. The real-time scheduling method of virtual scene based on multi-threaded entrance is used to load and render the virtual scene in real time according to the movement trend of the virtual avatar, which ensures the fluency of interoperability in terms of function and performance, so as to achieve the purpose of improving the training effect.

1. Introduction
The ground equipment system of the space launch site is a comprehensive complex system which integrates mechanical, hydraulic, automatic control and computer science. The normal operation of the ground equipment system is a strong guarantee for the successful launch of the spacecraft. Therefore, it is of great significance to diagnose and analyze the faults in the work and remove them in time. However, the large-scale equipment in the ground equipment system is the majority, and the cost of operation and maintenance is high [1] so the teaching and training of fault diagnosis on the real installation will produce huge cost.

Virtual fault diagnosis training system uses virtual reality technology to simulate the actual environment of the space launch site, so that trainees "immerse" in the virtual scene. Through the study and training of the working principle of key ground equipments and the troubleshooting mechanism of typical fault phenomena, the trainees can master the skills of equipment state identification, fault location and troubleshooting. The virtual fault diagnosis training system plays an important role in improving students' fault diagnosis training level and maintenance training ability.

2. The function of the system
The ground equipment of space launch site is composed of many kinds of large equipment and its control system. In order to make trainees fully understand the working principle of ground equipment system and improve the ability of fault diagnosis and maintenance, virtual fault diagnosis training system provides users with the functions of system composition and working principle display, equipment disassembly process demonstration, fault phenomenon simulation, fault diagnosis and maintenance process animation demonstration, etc. At the same time, the user can control the virtual
prototype in the virtual environment of the launch site, and train the tasks of fault injection, fault
diagnosis and troubleshooting [2].

Therefore, the virtual fault diagnosis system needs to realize the following functions:
A. It should have a visual operation interface with good human-computer interaction, so that the
operator can operate the equipment interactively in three-dimensional scene.
B. It shall be able to display the working principle, typical fault phenomenon, fault diagnosis
process and troubleshooting operation process of each system dynamically, so that the operator can
understand the working principle of the system and the fault diagnosis process.
C. By using the mouse and other interactive peripherals, the operator can get the training and
examination of equipment disassembly and assembly, in the three-dimensional scene.
D. The instructor has the authority to set up training subjects and manage trainees' training
information. According to the training program requirements of the trainees, the instructor will set up
various learning and training subjects for the trainees and distribute the related resource packages to
the trainees through the network.
E. Fault points can be injected into trainees’ training process according to fault phenomena and
distributed to trainees' platform. Trainees complete fault diagnosis and troubleshooting training
according to the system guidance, and then acquire new training tasks and operation skills, so as to
achieve the purpose of mastering correct operation procedures and improving fault diagnosis ability.

3. Design of the system architecture

The virtual fault diagnosis system consists of four parts: 3D simulation engine, database module, fault
diagnosis and analysis module and system management module [3].

The structure of virtual fault diagnosis system is shown in figure 1, and the specific functions of
each functional module are as follows:

![Figure 1. Virtual Fault Diagnosis Training System Architecture.](image_url)

3.1. 3D simulation engine

The 3D simulation engine includes two functions: 3D scene management and human-computer
interaction control. 3D scene management establishes a realistic virtual operating environment for
trainees, mainly including the loading of scene model, the simulation of terrain, sky and other
environments, as well as the simulation of water, fog and other particle effects. At the same time,
according to the change of virtual prototype state in the process of human-computer interaction and
the operation of virtual roles, the virtual environment is managed, refreshed and rendered in real time.
According to the established motion mapping relationship between users and virtual roles, the
human-computer interaction control function can detect the collision behavior in the virtual
environment, and simulate the output of real auditory and visual signals by collision processing to
improve the user's immersion.

3.2. Database module

The database module includes four types: basic information base, resource base, business logic base
and assessment base. The database structure is shown in figure 2. Basic information base is used to
store the information such as personal information, system configuration information and other basic information. The resource library is used to store the three-dimensional model, the three-dimensional animation of the system principle, the three-dimensional animation of the equipment disassembly and assembly, the map, the sky ball and other resources. Business logic library is used to store fault information, troubleshooting process information, equipment disassembly process information, etc. Training base is used to store training tasks, training results and other information. The above four types of databases are planned in accordance with data exchange standards and data standard system.

![Database Structure](image)

**Figure 2.** Database Structure.

### 3.3. Fault diagnosis and analysis module

The fault diagnosis and analysis module mainly describe the knowledge of troubleshooting, including the process knowledge and control knowledge of fault diagnosis. Process knowledge is the action sequence of the whole fault location and troubleshooting process. Control knowledge is to monitor the whole process of fault diagnosis and elimination, to identify and record the misoperation, and to provide the guidance of human in specific mode.

### 3.4. System management module

The system management module includes four parts: user management, authority management, course management and fault injection. The user management function allows you to create, modify, delete and view user information. User roles can be defined and different business permissions can be assigned through the permission management function. The course management mainly realizes the training subject setting and directional release function. Through fault injection, users can inject several fault points according to typical fault phenomena, and release the fault phenomena to trainees.

### 4. Process design

Fault diagnosis training is a kind of integrated training, which is a series of working processes of finding fault phenomena, finding out fault causes and troubleshooting. The system should simulate the typical faults of the ground equipment of the launch site, and transfer the fault cause from the fault library by fault injection. After fault injection, the system simulates the corresponding fault phenomenon and sets the state of the equipment model affected by the fault reason. Trainees judge the
fault imagination, check and diagnose the status of relevant equipment with auxiliary equipment such as instruments and mechanical tools, analyze the relationship between the fault phenomenon and the fault reason, find the fault reason, and conduct troubleshooting training. The specific working principle is shown in figure 3.

**Figure 3. Working Principle of Virtual Fault Diagnosis training system.**

The main workflow of virtual fault diagnosis training system includes two stages: fault injection and fault diagnosis training. In the fault injection stage, the administrator selects the fault components and the fault causes from the fault database to input to the system, which are involved in a certain fault phenomenon. According to the fault model in the fault database, the system outputs the fault phenomenon, updates the status of relevant equipment in the virtual environment, and publishes it to the training platform of the trainees. The fault injection process is shown in figure 4.

**Figure 4. Flow Chart of Fault Injection.**

After fault injection, trainees can observe and analyze the fault phenomenon in the visual training platform, and use virtual tools to detect and diagnose the running state of the virtual prototype in the
system, analyze and locate the cause of the fault, and carry out troubleshooting training. The specific training process is shown in figure 5.

5. Key technologies

5.1 Virtual fault diagnosis technology

Fault diagnosis module is the core of virtual fault diagnosis training system. The common fault diagnosis methods include fault tree analysis and expert system diagnosis. Fault tree analysis is a kind of graphic analysis method, which is intuitive and transplantable. However, it is difficult to diagnose the fault of the complex large-scale system such as the ground equipment of the launch site, has strong ability of logical reasoning and solution, and adopts modular structure, which has better expansibility and is conducive to the update of fault database. Therefore, the combination of expert system and fault tree analysis is used to realize virtual fault diagnosis, so as to improve the accuracy of fault diagnosis and the timeliness of fault database updating. The fault diagnosis module includes the construction of knowledge base and fault diagnosis reasoning.

5.1.1 Knowledge base building. In order to express the knowledge more intuitively and completely, the diagnosis instructions are expressed by the combination of production rules and framework. The fault tree is divided into a group of minimum fault trees. Each minimum fault tree can be transformed into one or more production rules in the diagnosis knowledge base, as shown in figure 6 [4-5]. The bottom event of each minimum fault tree can be used as the conclusion part of the rule in the knowledge base. The path of fault tree from top event to event analysis can be regarded as the precondition of knowledge base rules. The way of building knowledge base by fault tree makes the knowledge base highly modular and extensible.
5.1.2. Fault diagnosis reasoning. The reasoning process of fault diagnosis is based on the fault phenomenon, using the knowledge stored in the knowledge base, according to certain strategies, reasoning through the rule framework, and finally completing the process of fault diagnosis [6]. When the logical relationship among the top event, intermediate event and bottom event of fault tree is clear, and the top event (if) and the corresponding bottom event (then) are expressed in tree structure, this expression can be combined with the rule knowledge representation method generated in expert system. The top event in the fault tree is regarded as the system fault phenomenon, and the intermediate event and the bottom event are regarded as the process and result of expert system reasoning. In addition, taking the importance of the bottom event as the priority of the reasoning rules, the expert system locates and checks the faults according to the priority of the reasoning rules, which improves the efficiency of the system.

5.2 Virtual scene management technology

Virtual scene management has an important impact on scene visibility culling and collision detection [7]. The space launch site has the characteristics of large-scale key equipment and complex structure. Therefore, under the condition of limited memory and graphics rendering ability, the management, real-time generation and rendering of virtual environment is the key to meet the real-time loading of virtual environment and the smooth interaction of the system. In this paper, the object-oriented modeling method is used to analyze the simulation objects in the launch site, to build the visual image of the virtual launch site, and then to manage the scene of the virtual launch site.

The fault diagnosis system of virtual launch site describes the visual image by combining the tree structure with the topological structure of entry object [8]. The virtual environment of the launch site is described in a tree structure longitudinally, and the topological relationship of each subspace is described by the entry object. The entrance object is a special shape object, which has three functions: loading and unloading space, drawing and entering space. It is a shape used to connect two spaces [9]. The virtual launch site is composed of spatial directed graph by the entry object. When the position of the virtual character in the scene changes, the subspace set can be obtained by deep traversing the scene and space directed graph of the character, so as to reduce the scale of real-time rendering scene and improve the real-time performance.

6. Application cases

Tower crane is one of the common equipment in the space launch range. Taking tower crane system as an example, virtual fault diagnosis training is carried out. The instructor can set the fault location and cause through the fault injection module, and issue the fault diagnosis task to the trainees. The training process is divided into two parts: virtual fault location training and fault removal simulation training. In the training of fault location, the system simulates the fault phenomenon and displays the fault tree.
Students select virtual detection tools to detect the equipment, judge the equipment to be checked in the next step, and finally locate the fault location and analyze the fault reason, under the guidance of fault tree. The fault location training is shown in figure 7. The advantage of this system is to combine 3D simulation technology and 2D graphical description technology, to show the fault phenomenon vividly, and to describe the fault location and analysis process intuitively. Through this system, students can learn fault location knowledge systematically and effectively improve the ability of fault identification and analysis.

![Figure 7. Fault location training interface.](image1)

When trainees successfully locate the fault and find out the cause of the fault, they will enter the troubleshooting training. The purpose of troubleshooting training is to improve the equipment replacement skills of students. In the three-dimensional scene, students select tools, disassemble the faulty equipment according to the disassembly sequence, and replace the faulty parts according to the equipment installation sequence, as shown in Figure 8. The fault maintenance training module displays the process of equipment replacement with 3D animation, and guides students how to choose and use tools correctly, and skilled equipment replacement process. During the course of troubleshooting training, the system evaluates the troubleshooting skills of the trainees from the perspectives of statistics of maintenance time, correctness of tool selection, correctness of replacement process, etc.

![Figure 8. Troubleshooting interface.](image2)
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