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Research on Virtual Maintainability Verification Method of EMU Engine

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Research on Virtual Maintainability Verification Method of EMU Engine

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Abstract. Aiming at the problem of insufficient maintainability design method of EMU engine, a method of using virtual simulation to verify maintainability design is proposed. This paper mainly studies the quantitative evaluation method of maintainability index, and provides the quantitative evaluation method of accessibility and operation space based on virtual maintenance, the quantitative evaluation method of maintenance human factors and the calculation method of maintenance time. Combining with the characteristics of EMU engine system, the scheme design of virtual maintainability design software system for EMU engine is carried out, and the specific process of maintainability verification is given. The efficiency and quality of engine maintainability design and evaluation are effectively improved, and the development cycle is shortened. It is an effective method to realize the parallel optimization design of engine maintainability for EMU.

1. Instruction

High speed railway is an important mode of transportation in modern society. China has the world's largest and fastest railway network. By the end of September 2015, the operation mileage of China's high-speed railway has reached more than 20000 kilometers; it is expected that by the end of 2020, the operation mileage of China's high-speed railway will reach 40000 kilometers, basically covering cities with a population of 500000 or more at the provincial capital level. Under the background of the large-scale development of high-speed railway, how to improve the reliability and maintainability of EMUs, and how to optimize the maintenance strategy reasonably are the key technologies to ensure the operation safety of high-speed railway.[1]

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The engine is the key component of EMU, which belongs to large-scale complex product, with the characteristics of complex system, advanced technology, precise equipment and so on. In the traditional product design process, the design and evaluation of maintainability are mainly carried out on the physical prototype. The maintenance process designer evaluates the maintainability of the product through the actual operation of the physical prototype, and feeds back the maintainability defects to the designer. According to the feedback information, the designer modifies the product design scheme, and finally ensures the good maintainability of the product through repeated prototype experiment and scheme modification. Due to the long manufacturing time and high cost of physical prototype, traditional methods are used to design and verify the maintainability of EMU, which greatly increases the design cycle and development cost.

With the rapid development of virtual reality technology, virtual prototype can be used instead of physical prototype for maintainability design and verification. The maintenance process of virtual prototype can be simulated in virtual environment. The real-time collision detection technology can truly reflect the problems in the process of product maintenance, so as to evaluate the maintainability design of the product. The development time of the product will be shorten greatly by using virtual reality technology to replace the traditional physical prototype for product maintainability design and verification.

2. Structure and principle of virtual maintainability verification system

The maintainability verification system based on virtual simulation is to simulate the maintenance operation in virtual maintenance environment, investigate the maintainability parameters such as the accessibility, visibility of maintenance objects, the working attitude of maintenance personnel, the ease of operation, maintenance time and environmental factors, and provide the verification results and modification suggestions. Reasonable maintainability design should make it convenient for maintenance personnel to observe and operate at any time, and reduce discomfort and fatigue as much as possible when maintaining a certain working posture for a long time.

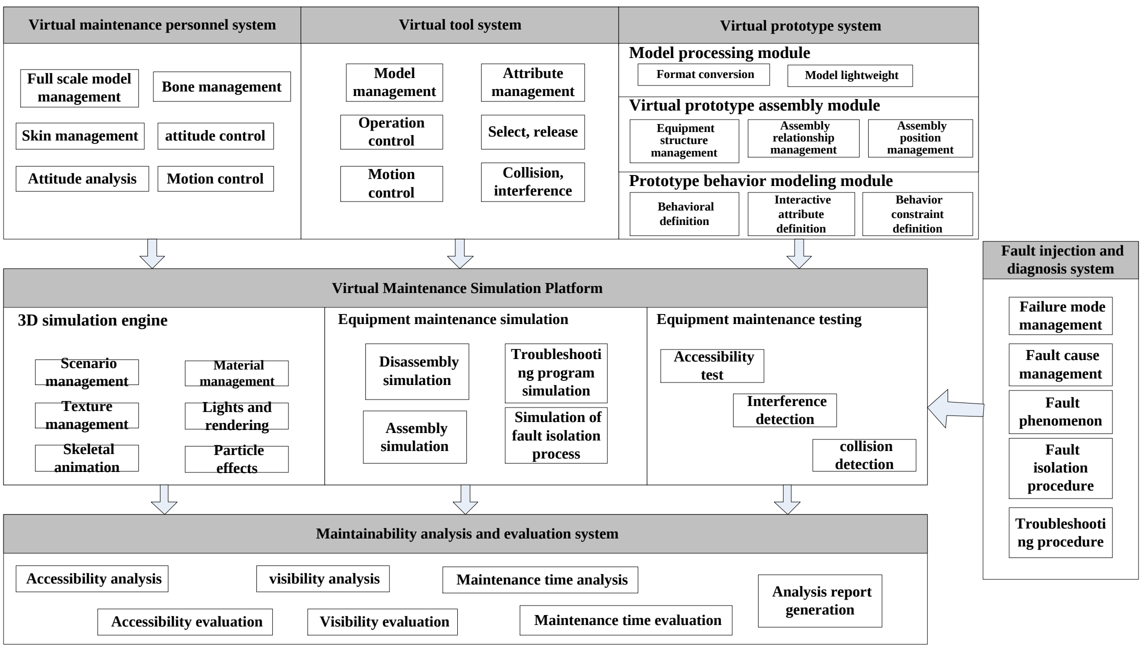

Figure 1. Architecture of Virtual Maintainability Verification System.

The maintainability verification system based on virtual simulation consists of virtual resource management system, virtual maintenance simulation platform, fault simulation system and maintainability analysis and evaluation system, as shown in figure 1. The resource management system mainly manages virtual maintenance personnel, tools, virtual prototype and other resources. Virtual maintenance simulation platform provides a unified display and rendering platform for virtual resources such as maintenance environment, virtual prototype and maintenance tools. At the same time, the accessibility, interference and collision detection are carried out in the whole maintenance process, which provides the basis for the analysis and evaluation of the maintainability index. Fault simulation system mainly provides relevant data for virtual fault phenomenon simulation and maintenance process simulation through fault mode management, fault isolation program management and other functions. The maintainability analysis and evaluation system obtains the results of collision detection, maintenance time and interference detection from the virtual maintenance simulation platform, and realizes the analysis and evaluation function of maintainability related indicators [2].

2.1. Virtual maintenance personnel management system

Full scale model management of virtual personnel: The model management of virtual maintenance personnel, which refers to the standard of ergonomics design for mechanical safety, is to establish the management database of key human body index parameters such as height, back of body, width between two elbows, arm length, hand length, etc. The 95th percentile or 5th percentile shall be adopted for the design of different key dimensions of human body according to the different maintenance working environment and different working postures. For example, when the whole body is used to enter the interior of the machine for maintenance, the statistical values of the 95th percentile personnel with height, body thickness and other parameters are used; when the forearm is used for maintenance, the statistical values of the 95th percentile personnel with forearm diameter, fist diameter and big arm diameter are used, and the statistical values of the 5th percentile personnel with arm length and hand length are used. Therefore, it can be ensured that the verification results of the maintenance verification system are applicable to 90% of the population, by using the full-scale human body model to manage the virtual maintenance personnel.

Bone Management: Bone management includes the management of bone geometry model, bone mathematical model, as well as the control algorithm of bone animation which combines joint animation with key frame animation.

Skin management: Skin management includes the management of virtual human skin and the management of different skin deformation algorithms.

Attitude Management: Attitude Management is to establish attitude database for virtual human, to manage the attitude of human in the process of maintenance, and to manage the comfort evaluation algorithm of attitude with holding time.

Action management: Action management mainly establishes action database for typical actions of virtual human in the process of maintenance, and manages parameters such as action range, action range and maintenance efficiency.

2.2. Virtual tool management system

Model management: There is a large number of general and special maintenance tools, which are used in the process of equipment maintenance. Model management is the unified management of the geometric model of the virtual tools used in the maintainability virtual verification platform.

Tool attribute management: Tool attribute management is mainly to manage the size, weight, type, description information, operation object, work constraint and other related attributes of the tool.

Selection and release: The selection and release of tools are realized by collision detection algorithm. In the virtual tool system, the information such as collision bounding box and operation position of tools are defined and managed uniformly.

Operation control: The operation control is aiming at analyze the function and operation object of the tool, manage the operation track and operation mode of the complete operation stroke of the tool, and adjust the operation track of the tool in real time through collision detection to realize the operation control of the tool.

2.3. virtual prototype

The virtual prototype system mainly consists of model processing module, prototype assembly module and prototype behavior modeling module. The model processing module mainly realizes the model format conversion function and model lightweight function. It loads the engineering model of the prototype into the model library of the maintainability verification system through the format conversion and model lightweight processing. The assembly module of virtual prototype mainly includes the functions of model structure management, assembly relationship management, assembly orientation relationship, etc. through analyzing the structure of the model and the related relationship, the assembly relationship and the mutual constraint relationship of the model are obtained as the basis of the maintenance process design. The prototype behavior modeling module mainly includes behavior definition, interaction attribute definition, behavior constraint definition and so on. Through the analysis of the working principle of the prototype, the behavior mode of the prototype and the behavior constraints between parts are modeled, and the behavior model of the prototype is obtained as the principle verification model of the maintenance results.

2.4. Virtual Maintenance Simulation Platform

The virtual maintenance simulation platform mainly includes three-dimensional simulation engine, equipment maintenance simulation management, equipment maintenance detection and other functional modules. In the three-dimensional simulation engine, it mainly realizes the management of scene, material, texture, light and rendering, skeleton animation, particle effect and so on. It provides a variety of maintenance scenarios for the virtual maintenance simulation platform, and can select and configure the maintenance environment, workshop specifications, lighting conditions, weather conditions, etc. according to the actual conditions of equipment maintenance. The simulation of equipment maintenance mainly realizes the simulation of disassembly and assembly process, fault isolation process, Troubleshooting procedure and maintenance process. Through the dynamic collision detection of the maintenance simulation process, the equipment maintenance detection module finally realizes the reachability and visibility detection of maintenance and collision detection in the maintenance process, as well as the interference detection of parts in the operation process of the equipment after the completion of maintenance, which provides the basis for the verification and evaluation of maintenance.

2.5. Maintainability analysis and evaluation system

Maintenance analysis and evaluation system mainly includes maintenance visibility analysis and evaluation, accessibility analysis and evaluation, analysis report generation and other functional modules.

Maintenance visibility refers to the visual accessibility of the repaired object in the process of equipment maintenance, that is, the visibility level of the scope that can be seen from one or more positions. The visual cone method is used to analyze and evaluate the maintenance visibility. According to the man machine engineering design criteria for military equipment and facilities, when the head is kept upright and only the eyes rotate, the maximum field of vision of human beings is within the range of 25 degrees upward and 35 degrees downward of the horizontal line, 35 degrees left and right respectively; the best field of vision of human beings is within the range of 0 degrees downward of the horizontal line, 15 degrees left and right respectively. According to the best vision and the maximum vision of human beings, the vision cone of the best vision and the maximum vision is established, and then the visibility of equipment maintenance is evaluated. It is generally believed that when the visual evaluation value of the repaired work pieces in the best visual field is 0.7-1, the visual evaluation value in the maximum visual field is 0.4-0.7.

Maintenance accessibility refers to the accessibility of the repaired or replaced parts in the process of equipment maintenance. Equipment maintenance accessibility is evaluated by collision real-time detection technology, which mainly includes physical accessibility and operation accessibility. Physical accessibility evaluation refers to the evaluation of whether the maintenance personnel and tools collide with other objects and whether the maintenance work pieces can be reached after the maintenance personnel select the tools and enter the maintenance space according to a certain planning path. Operation accessibility evaluation refers to the evaluation of whether maintenance personnel and tools have enough operation space, and whether personnel posture is comfortable during the maintenance process.

The analysis report mainly includes three parts: maintenance plan, process inspection and evaluation results. Maintenance scheme refers to the recording and display of maintenance steps, selected virtual maintenance personnel parameters, tools, etc. Process inspection refers to the recording and display of the movement track and collision results of personnel and tools in the maintenance process. The evaluation result refers to the record and display of the evaluation result obtained by the relevant evaluation module for maintenance visibility and accessibility. Provide the basis for the designer to modify the equipment scheme.

3. Maintainability verification process design

The workflow of the virtual reality based maintenance verification system of EMU engine is shown in figure 2. The specific workflow is as follows [3]:

1) The operator logs in the maintainability verification system and selects the maintenance scenario, including the selection of maintenance workshop and site, and the configuration of weather, lighting and other light conditions.

2) The system loads equipment and workshop model, and constructs virtual maintenance environment.

3) The operator shall determine the failure mode and formulate the failure isolation procedure and failure maintenance procedure.

4) The user selects the human model, configures the key parameters, and then selects the maintenance tools needed in the maintenance process. The system loads the human model and tools into the virtual maintenance scene. Then, the repair preparation is complete.

5) Virtual maintenance personnel perform maintenance tasks in virtual workshop. The system uses real-time collision detection technology and visual cone method to judge the maintenance visibility and entity accessibility. If the maintenance object is not in the reachable space and visible range, the

system traverses all the reachable paths of the human body model, and re plans the motion path until the operation object is in the reachable space and visible range of the maintenance personnel and tools. Then, the motion path is determined and recorded.

6) After the attitude of maintenance personnel is determined, the system judges the comfort of human body attitude. The system traverses all possible postures of the human body model on the basis of satisfying the visibility and accessibility of the repaired object, and adjusts the posture of the maintenance personnel, if the posture of human body does not conform to the normal range of motion of human joints. Finally, the reasonable maintenance attitude of maintenance personnel is determined and recorded.

7) The system evaluates the operation accessibility, that is, whether the virtual tool and the virtual maintenance personnel interfere or collide with the maintenance object in the maintenance process. In case of collision, properly adjust the attitude of maintenance personnel and operation range of maintenance tools, and carry out collision detection again until there is no collision between maintenance personnel, tools and repaired objects in the process of maintenance. Finally, the position and attitude of maintenance personnel and the operation path of maintenance tools are determined and recorded.

8) After determining the optimal access path, maintenance position, operation attitude and tool operation path for each step in the fault isolation procedure and Troubleshooting procedure, the maintenance process is simulated.

9) The maintenance time of each maintenance step is analyzed and evaluated based on the reachable path, operation attitude, weight of virtual tool, operation range, operation mode and other factors.

10) According to the maintenance time of each maintenance step and the attitude of personnel in the maintenance process, the comfort of each maintenance step is analyzed and evaluated.

11) Based on the accessibility, visibility, maintenance time and operator comfort of each maintenance step, the whole maintenance process is analyzed and evaluated, the analysis report is obtained, and suggestions for design modification are put forward.

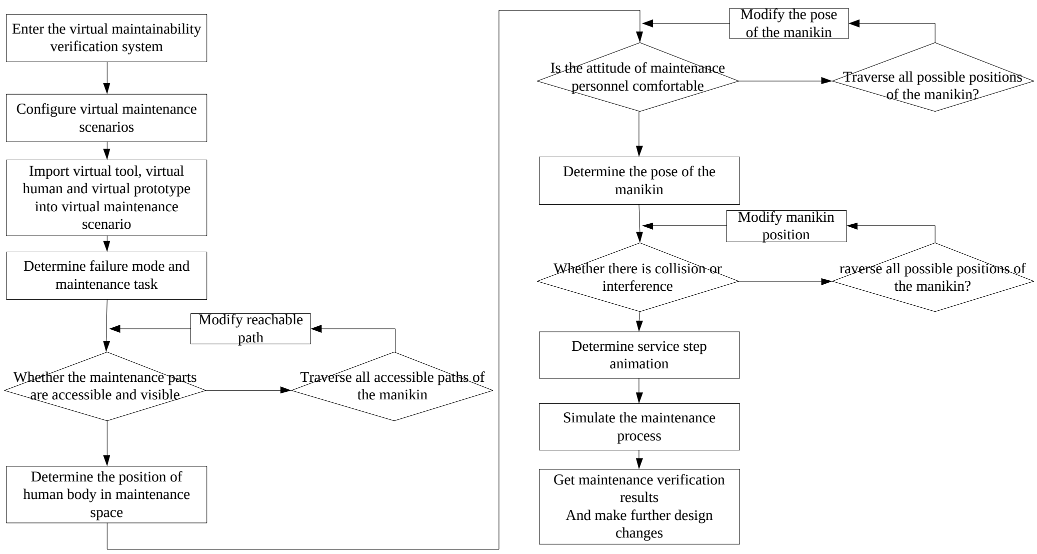

Figure 2. Workflow of Maintainability Verification System

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4. Research on maintainability evaluation method

4.1 Reachability quantification and operation space quantification based on virtual maintenance

4.1.1. Quantitative evaluation method of entity reachability. Physical accessibility refers to the degree to which tools or hands can approach the maintenance part along a certain path or way. The quality of physical reachability is related to the size of the reachable region of human body. It can be considered that the reachable region is the largest reachable region formed by human arm. If the operation position deviates from the accessible area of the operator even beyond the accessible area during the actual maintenance operation, it is difficult for the operator to finish the operation accurately; moreover, the closer the object is to the human body, the easier the maintenance personnel can reach it, the better the accessibility[4].

In the virtual maintainability design software system, the expert scoring method is introduced to realize the quantitative evaluation function of entity accessibility. Experts can judge the accessibility according to the relative position of the maintenance object and the arm envelope space in the virtual environment, and grade the accessibility of the current operation.

4.1.2. Quantitative evaluation method of visual accessibility. The visual accessibility (visibility) of maintenance personnel refers to that the maintenance part is within the range of the maintenance personnel's sight, so that the maintenance personnel can carry out maintenance activities conveniently. For example, when removing parts, all parts shall be visible from a normal perspective; when removing and placing parts, parts shall be visible from the opening part; when configuring parts, metal parts, screws, clamps, etc. on parts shall be visible without being covered by other parts, or by the hands and tools of maintenance personnel; parts to be adjusted shall be visible and adjustable.

Based on the visual observation rule of human, the maintainability verification system constructs the visual cone model of maintenance workers in the maintenance process, and sets different visual cone angle values to judge whether the maintenance of the product structure has good visibility. According to the visual cone model in virtual environment, the quantitative evaluation method of visual accessibility can be obtained based on expert evaluation method. When experts evaluate the visual accessibility of maintenance personnel in the virtual environment, they can score according to the position of the repaired object within the operator's visual cone. The evaluation criteria for entity accessibility are shown in table 1[5].

Table 1. Evaluation criteria of entity accessibility

Target	Description	Score
Physical accessibility	During the whole maintenance process, both the maintenance object and internal operation can be directly seen.	1
	Before performing a repair action, the repair object can be seen directly. However, during the maintenance operation, due to the block of body or maintenance equipment / tools, the maintenance object is not visible, but the maintenance operation is visible.	3
	Before performing a repair action, the repair object can be seen directly. However, during the maintenance operation, due to the block of body or maintenance equipment / tools, the maintenance object is not visible. At the same time, the maintenance operation is not visible.	5
	During the whole maintenance process, the maintenance object and internal operation cannot be seen directly, mainly relying on the feeling, experience and technical level of maintenance personnel	8

4.1.3. Quantitative evaluation method of operation space. The maintenance space of products refers to whether the structural design of parts has enough operation space, which is mainly related to the structural design and layout of products. The reachability of maintenance space can be evaluated by working space R.

$$R = \frac{V}{V_{min}} \tag{1}$$

Where: V is the working space; $V_{min}$is the minimum working space, when the operating position and maintenance tools are determined, $V_{min}$is the fixed value.

In the virtual environment, the size of the job space is measured, and the job space ratio R is calculated according to the measurement data. According to the experimental statistical data, when R > 1.5, it can be considered that the working space of the maintenance part is better, that is, generally there is no collision and interference in the maintenance process.

4.2 Human element quantitative evaluation technology based on virtual maintenance

The maintenance work can not be carried out without the participation of people, whose factors will directly affect the maintenance results. Whether the operators participating in the maintenance can operate comfortably and efficiently directly affects the maintenance results. Therefore, in the engine design stage, considering the man-machine work efficiency and reasonably designing the engine structure can effectively avoid the fatigue of maintenance workers, improve the maintenance efficiency and reduce the maintenance accidents caused by human factors [6].

As the result of posture analysis in maintenance simulation is only for a certain work posture, it can not represent the comfort of the whole maintenance process. In view of this situation, the evaluation model of overall posture comfort of maintenance engineering is proposed as follows:

$$R = \frac{\sum_{i=1}^{n} R_i \cdot T_i}{\sum_{i=1}^{n} T_i} \tag{2}$$

Among them, R is the overall posture comfort during maintenance, $R_i$is the RULA score of the i-th typical maintenance posture, and T_i is the duration of the i-th typical maintenance posture.

4.3 Maintenance time calculation method based on Virtual Prototype

Maintenance time is the net labor time for maintenance personnel to carry out maintenance work. Maintenance time is one of the important evaluation indexes of maintenance efficiency. Accurate maintenance time can reflect the time consumption of completing maintenance tasks, which is of great significance for the timely use of products. There are two methods to determine the maintenance time: PTS and CAA. They have their own advantages and disadvantages. So the system combines the two methods to determine the maintenance time efficiently and accurately.

A maintenance task can be divided into multiple work units such as disassembly, replacement and repair. To complete each work unit, multiple actions need to be performed. Therefore, a maintenance task can be divided into three levels: maintenance task level, work unit level and action unit level. Since the time of action unit layer can be determined by MODAPTS, the operation time of the whole maintenance activity is also determined accordingly. The total time model of maintenance events is:

$$T = \sum_{i=1}^{m} T_i = \sum_{i=1}^{m} \sum_{j=1}^{n_i} T_{ij} \tag{3}$$

Where, T is the total time of maintenance work, Ti is the time of the i-th maintenance work unit, Tij is the time of the j-th action unit in the i-th maintenance unit, M is the number of work units in the maintenance time, and Ni is the number of action units included in the i-th operation unit.

At present, in the human motion simulation module of DELMIA, a common virtual maintenance software, two methods of operating virtual human are provided. One is to give the time value needed by human activities. The program determines the speed of virtual human movement by calculating the given time value and the moving distance of virtual human. Virtual human will move along the speed smoothly. The other is to specify the movement speed of virtual human. The program calculates the given speed and movement distance to get the time needed for maintenance activities [7]. The so-called designated speed here is not to give a certain value, but to give a ratio to the normal speed, and the ratio should be set according to different activities.

Because in the actual maintenance activities, the maintenance operators can not always maintain the same speed to do uniform movement, but change according to the specific action. Obviously, if only using the computer-aided method to get the maintenance time is not very accurate. MODAPTS takes this factor into account, and through a large number of experimental analysis, we get the pre-determined time standard of each movement, which conforms to the objective situation. Therefore, in this paper, the maintenance time is determined by the combination of MODAPTS and maintenance simulation.

When the computer is used for simulation analysis, the maintenance time can be quickly obtained, but the accuracy is not enough. Using the MODAPTS method, the maintenance task is decomposed to the maintenance action layer, and the maintenance time is calculated according to the time value of each maintenance action. It is a more accurate and credible method to determine the time, but the method is relatively cumbersome compared with the simulation analysis. Therefore, according to the characteristics of maintenance tasks, the maintenance time can be obtained accurately and efficiently by segmenting tasks and adopting different methods in each task segment.

5. Conclusion

Maintainability analysis and verification is a complex system engineering. In this paper, the maintenance process of EMU engine is simulated by virtual simulation, and the maintainability is verified and evaluated by dynamic collision detection. To solve the problem of long design cycle and high cost of traditional physical prototype for maintainability verification. In the future, the specific modeling method of virtual prototype should be further studied based on the characteristics of each system of EMU engine.

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