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Modeling of Task Establishment and Allocation for Collaborative Virtual Maintenance Training of Complex Equipment

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Abstract: In this study, we propose the maintenance task establishment method based on fault simulation models. Maintenance task allocation model based on Multi-Agent System and High Level Architecture is presented to manage and coordinate the dynamic task allocating process of multi operators and it can make the intelligent decision for their collaborative maintenance operation at each step. Object information template is designed with the Extensible Markup Language to perform interactive communication of the heterogeneous data and information in the different models of collaborative virtual maintenance training system, which ensures the efficient share of the data resource for the collaborative maintenance operations. Finally, the simulation research on a mechanical-electronic-hydraulic integrated subsystem in complex equipment is done and the simulation execution and results show the effectiveness of the proposed methods.

Keywords: Collaborative virtual maintenance, fault simulation, maintenance task allocation, maintenance task establishment, multi-agent system, object information template

INTRODUCTION

Inthe modern industrial plants, both the operators and maintenance staffs are required to be knowledgeable to remove the faults of complex equipment in time. As the equipment are composed of Mechanical-Electronic-Hydraulic Integrated System (MEHIS), the maintenance process is so complex and difficult that will cause excessive expenses and unexpected damage when taking the maintenance training with actual equipment and it also requires the teamwork of multi departments and operators. The single person training mode provided by Virtual Maintenance System (VMS) can not meet the actual requirement of maintenance training any longer. Whereas, techniques of Collaborative Virtual Maintenance (CVM) provide effective approaches to the maintenance training of complex equipment. In comparison with the traditional methods, it has the characteristics of high reusability, resources sharing, more interaction and immersion, low cost, easy to maintain and extend. However, the existed researches and training systems mainly focus on the planning, teaching and training of maintenance process (Kashiwa *et al*., 1995; Yang *et al*., 2006; Li *et al*., 2003), such as the disassembly, replacing and assembly of defined parts and components, or the maintainability analysis and human factor analysis. As the purpose of maintenance is to detect and replace or repair the fault components to make equipment work normally, the training contents should take maintenance operation of fault components as well as the relevant fault mode, detection and location and the maintenance task establishment and allocation into consideration.

Based on the fault injection and diagnosis simulation with simpler fault simulation models, maintenance task of CVM for the complex equipment is established and allocated dynamically to each operator with MTAM through the maintenance operation process of fault parts and components. The XML-based OIT which represents collaborative operation information of multi operators is established to perform the interactive communication of heterogeneous data and information in CVMTS. Finally, a case study is conducted with experimental simulation of subsystem in complex equipment, which has shown that the proposed methods worked effectively in the collaborative maintenance training of complex products.

LITERATURE REVIEW

Fault simulation modeling of complex system: Fault simulation modeling methods have been studied diffusely since the 1990s and many researches have been worked out. The fault simulation and modeling methods were proposed earlier for the combinational circuits (Maamari and Rajski, 1990; Takahashi *et al*., 1994) and then utilized widely in the electronic system (Zhao *et al*., 2007; Lin *et al*., 2007).

With the development of computer and simulation techniques, fault simulation and modeling methods are studied and applied gradually in the field of complex equipment and system. Fault simulation modeling method based on physical model and virtual prototype was proposed for integrated mechanical and hydraulic equipment to analyze and simulate their various fault modes and obtain the different fault samples (Chen *et al*.,

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2007; Lin *et al*., 2007; Yin *et al*., 2008). Fault simulation modeling method based on structural and functional models of system was presented for the simple device system to obtain the quantified relation of symptoms and faults and the potential faults modes. Then these methods were studied and applied in the complex systems to analyze their dynamic characteristics and fault patterns for the intelligent fault diagnosis. Aiming at the demands of maintenance planning and training, some researchers have made great efforts to introduce these methods into the field of Virtual Maintenance (VM).

Through the analysis above, fault simulation modeling method based on physical model and virtual prototype is applied more and more widely in complex system, but only a few literatures concentrate on the combination of fault simulation and maintenance training. So the main target of fault simulation modeling in this study is to build the simpler fault simulation and diagnosis models, which can simulate the fault parameters of MEHIS, define the maintenance task by injecting, detecting and locating the fault component and support fast interaction and communication in Collaborative Virtual Maintenance Training System (CVMTS).

Maintenance task allocation modeling: The MTA for complex equipment has been concerned by researchers during the last decades, but it is till at the exploratory stage. Zhu *et al*. (2003) established the Maintenance Task Allocation Model (MTAM) based on multiunit according to given resources allocation schemes, load capacity of maintenance teams and maintenance process, which includes: maintenance teams selecting, maintenance tasks selecting and task allocation model establishing. Hu *et al*. (2011) created a simulation model between maintenance tasks and resources for complex equipment based on Colored Petri Nets (CPN) and the switch rule was proposed. Jia built the mission editor background based on fault tree to add fault type and phenomenon for maintenance mission training. Lin *et al*. (2007) constructed a maintenance mission planning strategy based on genetic algorithm, which combined with equipment maintenance procedure and aims to minimizing the overall maintenance time. Chen proposed the synchronization optimal mode1 for multiple repair tasks to minimize the repair cost in per cycle.

In the researches above, the related studies on MTA modeling are mainly focused on maintenance resource allocation and task scheduling for the actual maintenance decision. There was hardly a literature that focuses on the MTA in VM or CVM. As the purpose of CVM is to provide an effective approach to training the maintenance operation of complex equipment for the operators in different workstations, its MTA modeling is a key issue should be concerned about, which can assign the maintenance task for each operator reasonably and make their maintenance operation collaboratively.

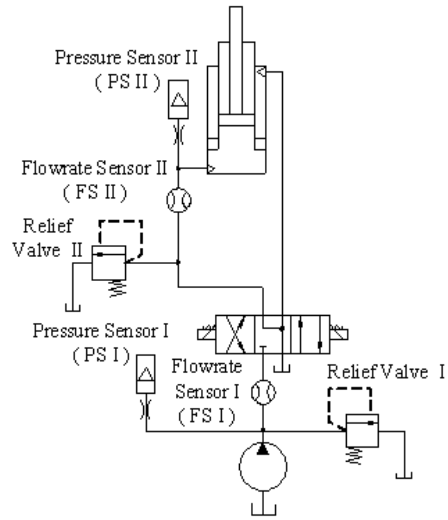

Fig. 1: Prototype system of a certain MEHIS subsystem

METHODOLOGY

Maintenance task establishment of CVM:

Physical simulation analysis of complex system: The prototype system and simulation model of a certain MEHIS subsystem in large-scale complex equipment are displayed respectively in Fig. 1 and 2. As the simulation model is created with AMESim and the physical character parameters of the modules of hydraulic components, multilevel cylinder, variable flowrate and variable load control are configured with the practical parameters of actual components, so the physical characteristics such as gravity, collision, friction resistance, hydraulic leakage and impact can be reflected more factually and the state parameters in each executing phase of the working process can be studied, analyzed and confirmed as well.

In the subsystem as shown in Fig. 1, the multilevel cylinder is the final actuator and its dynamic characters determine whether the physical simulation model of the subsystem is accurate and reliable or not. So its velocity and displacement during the simulation process is recorded in real-time to validate the veracity of physical model.

The velocity simulation curve of multilevel cylinder is shown in Fig. 3a and the displacement simulation curve is shown in Fig. 3b. From Fig. 3 that: the spread velocity of cylinder I and II has obvious disturbance as simulation began. When cylinder I collides with the inner wall of the end cover and stop spreading, cylinder II starts to spread while its velocity has stronger impact disturbance caused by the collision with cylinder body and the change of flowrate. Then cylinder II spreads smoothly till the end cover while cylinder I oscillates all the time that caused by hydraulic impact. Thus all of theses features reflect the working process of the actual subsystem factually and the simulation model established based on AMESim can

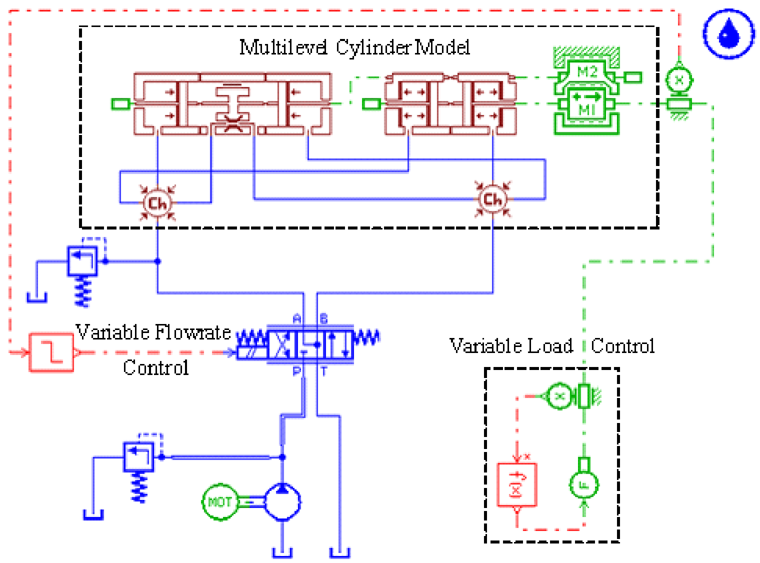

Fig. 2: Simulation model of a certain MEHIS subsystem

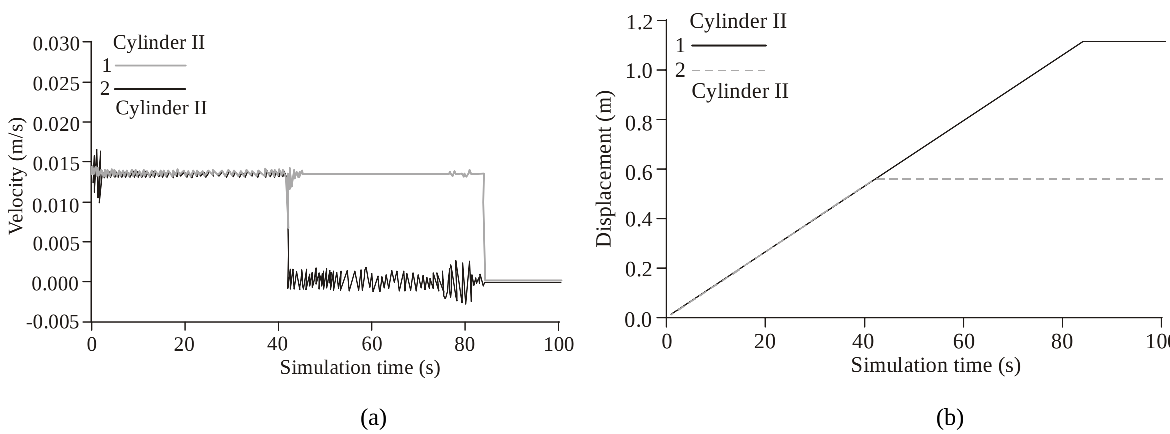

Fig. 3: The motion simulation curve of multilevel cylinder model

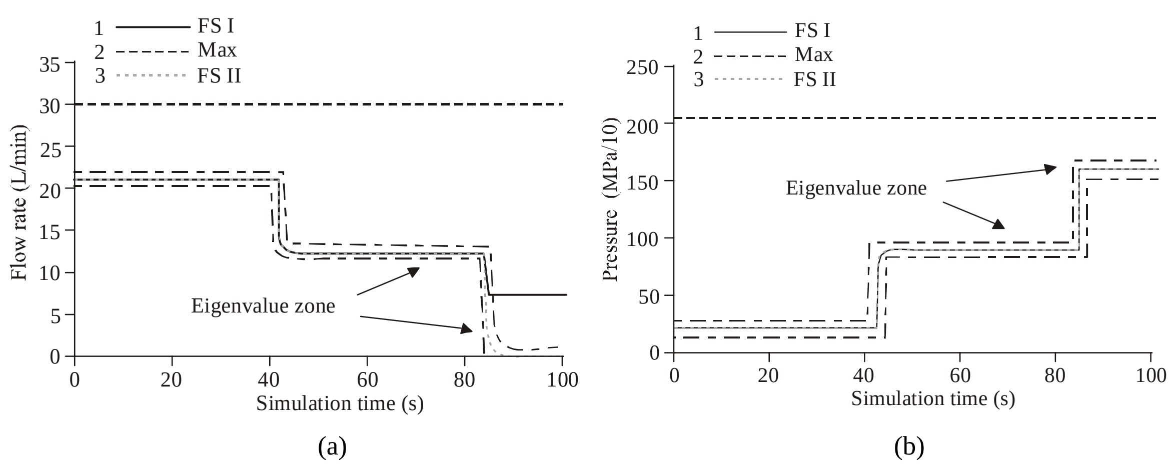

Fig. 4: The curve of normal flowrate and pressure of detection points

reflect exactly the physical characteristics, working process and state parameters of the actual subsystem. Accordingly it can replace the prototype system to implement the extraction of fault parameters and the simpler design of fault simulation model.

Fault simulation models of complex system: The fault simulation model of MEHIS is designed based on its physical simulation model. Its main function is to calculate the injected fault information and then set up the fault degree and state parameters of components and actuators with the injected fault information. Thereby the fault values of parameters in each loop are calculated and defined to simulate the various faults dynamically. As the fault information in Mechanical-Hydraulic System (MHS) is mainly mirrored in the abnormal pressure and flowrate, which may be caused by the faults of mechanical components or devices. So the fault simulation model can be simplified according to the maintenance training requirement and the main idea of its simpler design is:

Firstly, confirm the eigen values of normal parameters (flow rate and pressure) in each executing step of the sub-system i, as the curves of detection points FS I, FS II, PS I, PS II (Fig. 1) and the potential maximums of them are displayed in Fig. 4.

Then, analyze and confirm the range of potential fault values at this working step k, which are outside of the eigen value zones (surrounded by the shorter dotted lines).

Finally, set the weight coefficients of faults according to their type and degree. Thereby the fault eigen values of pressure and flow rate of each loop at relevant working step are confirmed.

Assume P_{ij} are the parameters of detection point j in subsystem i, $minP_{ij}$ and $maxP_{ij}$ are the potential minimum and maximum values of them respectively, thereby the ranges of parameters PR_{ij} can be described as follows:

$$_{\mathrm{Prij}} = [\mathrm{minP_{ij}}, \mathrm{maxP_{ij}}] \tag{1}$$

In order to make fault simulation model have certain fault tolerant performance, the fault tolerant efficiency is added to establish the eigen value zones as follows:

$$\mathrm{PEZ_{ijk}} = [(1\text{-}\mathrm{R_{ij}}/2)\mathrm{PE_{ijk}}, (1+\mathrm{R_{ij}}/2)\mathrm{PE_{ijk}}] \tag{2}$$

where, PE_{ijk} are the eigen values of normal P_{ij} at working step k. PEZ_{ijk} are the eigen value zones. R_{ij} is the fault tolerant efficiency. Then the range of potential fault values FP_{ijk} at working step k is expressed as follows:

$$\begin{cases} FP_{ijk} = PRi_j \cap \overline{PEZ_{ijk}} = HFP_{ijk} \cup LFPi_{jk} \\ HFP_{ijk} = \left[\left(1+ R_{ij}/2\right)PEi_{jk}, \max P_{ij}\right] \\ LFP_{ijk} = [\min P_{ij}, (1- R_{ij}/2)PE_{ijk}] \end{cases} \tag{3}$$

where, HFP_{ijk} are the regions of fault values above the PEZ_{ijk}, while LFP_{ijk} are the ones below. Then HFP_{ijk} and LFP_{ijk} are weighted suitably according to the fault types and degrees, thus the fault eigen values FPE_{ijk} of P_{ij} at working step k can be expressed as follows:

$$\begin{cases} FPE_{ijk} = \left(\sum_{m=1}^{N} W_{ijkm}\right)\left|HFP_{ijk}\right| + \left(\sum_{m=1}^{N} V_{ijkm}\right)\left|LEP_{ijk}\right| \\ \qquad + Min(FPR_{ijk}) \\ \left|HFP_{ijk}\right| = \max P_{ij} - (1+ R_{ij}/2)PE_{ijk} \\ \left|LFP_{ijk}\right| = (1- R_{ij}/2)PE_{ijk} - \min P_{ij} \end{cases} \tag{4}$$

where, $|HFP_{ijk}|$ and $|LFP_{ijk}|$ are the region lengths of HFP_{ijk} and LFP_{ijk}. FPR_{ijk} is the potential fault region that can only be valued as HFP_{ijk} or LFP_{ijk}. N is the number of fault types in the subsystem i. W_{ijkm} and V_{ijkm} are the weight coefficients of faults in HFP_{ijk} and LFP_{ijk}, which represent the influence trend of fault type m to detection point j in subsystem i at working step k. And they are mutually exclusive in pairs and used to define the fault type and degree. The constraint conditions are as follows:

$$\begin{cases} 0 \le W_{ijk} 1 \le and\ 0 \le \sum_{m=1}^{N} W_{ijkm} \le 1 \\ 0 \le Vi_{jkm} \le 1 and\ 0 \le \sum_{m=1}^{N} V_{ijkm} \le 1 \\ W_{ijkm} = 0, \qquad V_{ijkm} \ne 0 \\ V_{ijkm} = 0, \qquad W_{ijkm} \ne 0 \end{cases} \tag{5}$$

That is to say that one fault can not locate in HFP_{ijk} and LFP_{ijk} simultaneously. Considering the constraints in (5), (4) can be simplified as follows:

$$\begin{cases} FPE_{ijkm} = \left(\sum_{m=1}^{N} Wijkm\right)\left|HFP_{ijk}\right| + (1+ Rij/2)PE_{ijk}, V_{ijkm} = 0 \\ FPE_{ijk} = \left(\sum_{m=1}^{N} V_{ijkm}\right)\left|LFP_{ijk}\right| \qquad W_{ijkm} = 0 \end{cases} \tag{6}$$

Then fault modes and parameters of subsystems can be simulated with the physical models and (1)~(6), based on the weight coefficients of faults that gained from the experiential knowledge of fault components. In maintenance training process, the simulated faults can be injected dynamically into the executing CVMTS at any working step. So the operators can be trained to acquire practical skills of analysis and maintenance of different fault modes.

Maintenance task establishment of CVM: MTE of CVM is performed based on the fault simulation models and High Level Architecture (HLA) with the fault

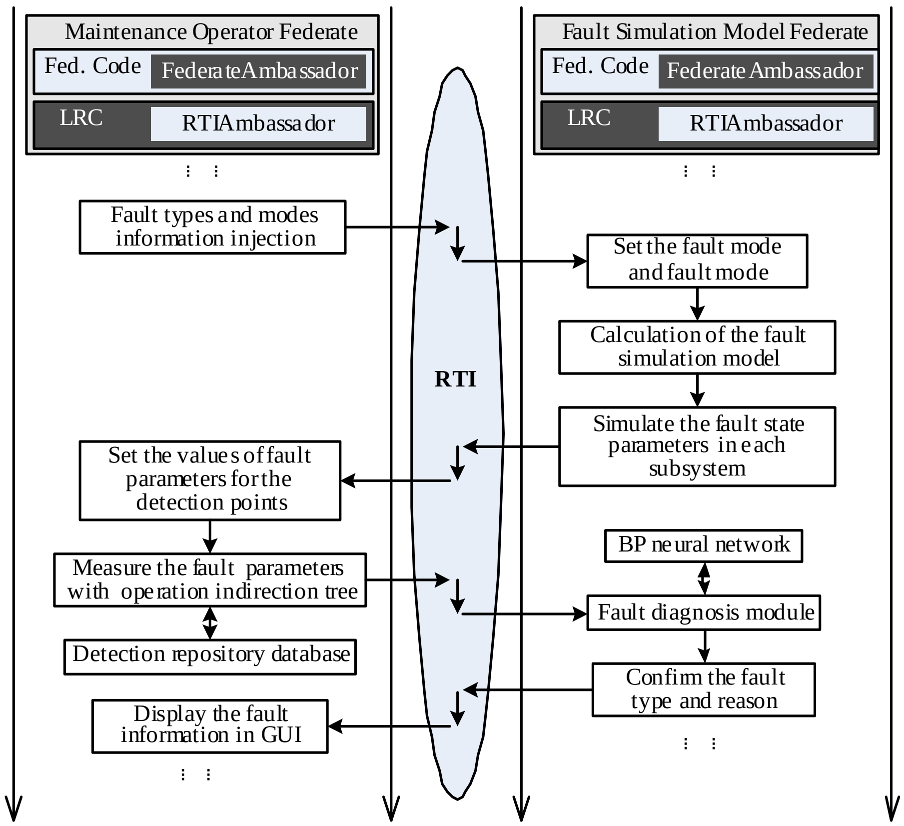

Fig. 5: The main workflow of MTE of CVM

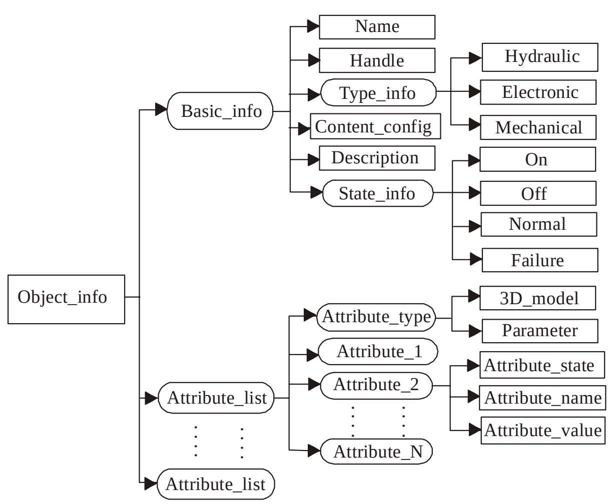

Fig. 6: The object information template in the format of XML

injection and diagnosis simulation. The main workflow of MTE for CVM and interactive communication of information between fault simulation federate and each maintenance operator federate are displayed in Fig. 5 and the detail process is as follows:

Step 1: Maintenance training teacher selects the fault mode and type with the Graphic User Interface (GUI) of CVMTS and then they are transferred to the fault simulation models for the further processing.

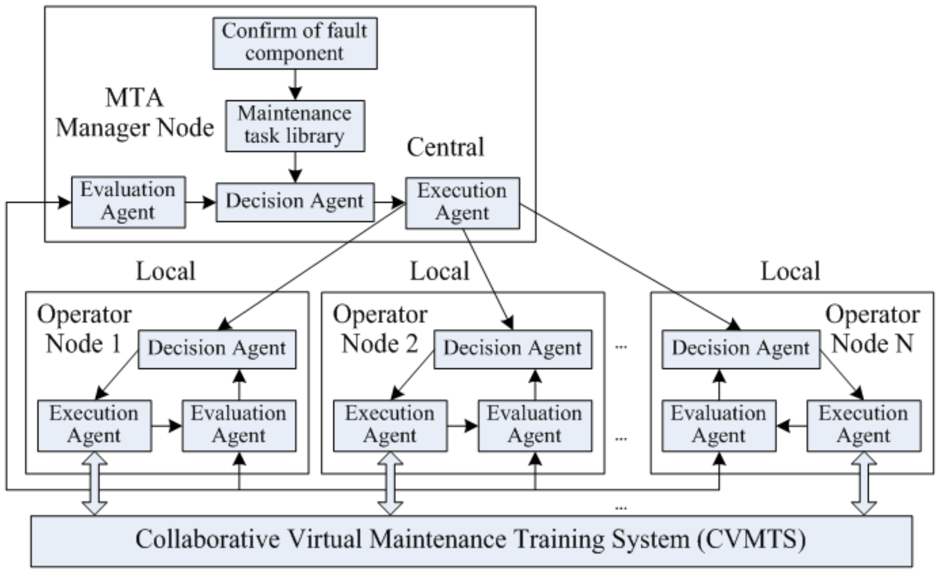

Fig. 7: The MTAM structure of CVM based MAS

Step 2: According to the selected fault types and modes, the fault parameters of subsystems are calculated by the fault simulation model. Then the fault parameters are inserted into the Object Information Template (OIT) to simulate the fault parameters in subsystems. The OIT is described in the format of Extensible Markup Language (XML) and includes the data and information such as name, handle, type, state, attributes and their values, description and so on, as shown in Fig. 6. As XML can display various characters through Unicode and is independent upon languages, the OIT can exchange the heterogeneous data and information of various models in MEHIS with different platforms or systems.

Step 3: Simulated fault information is distributed to the maintenance operator node in each workstation to set the fault parameters of detection points in the subsystems. And then each operator implements the state parameters detection according to the operation direction tree and detection repository.

Steps 4: State parameters measured by the operator in each workstation are sent back to the diagnosis module to be analyzed and processed further. After the integrative calculation and analysis of these parameters, the fault information confirmed is returned back to the relevant workstation.

Step 5: The fault component and corresponding reason is displayed in the GUI of each workstation node and the maintenance task is established for the trainees.

Maintenance task allocation model of CVM:

Maintenance task allocation of CVM: As the purpose of MTA of CVM is to distribute the task and operation planning to the departments and operators for collaborative virtual maintenance training in Local Area Network (LAN) or Wide Area Network (WAN) and the dynamic allocation and decision of the confirmed maintenance task is the key issue to be studied. So the Multi-Agent System (MAS) base on HLA is applied to manage and coordinate the allocating process for all the trainees. And the MTAM structure of CVM is shown in Fig. 7, which regards the MTA manager module and the operator module in each workstation as relatively independent Agent node. Each Agent node is composed of the Decision Agent (DEA), Execution Agent (EXA) and Evaluation Agent (EVA), which can be considered as the Agent Unit (AU).

The main process of MTA can be expressed as follows: Firstly, after the fault components are confirmed, the central DEA in MTA manager node will receive the task information sent by the maintenance task library, which stores the maintenance task sets with operation planning and steps of the component assembly in different fault modes.

Secondly, the central DEA analyzes the maintenance planning and steps according to maintenance regulation and workflow model provided by the CVMTS to decide the maintenance contents that the operator in each workstation should accomplish.

Thirdly, the maintenance contents are distributed by the central EXA in MTA manager node to the local DEAs in operator nodes. Then each local DEA analyzes the corresponding maintenance contents to determine the operation steps and workflow and sends the decision information to the related local EXA in the same AU to implement maintenance instruction, operation detection and state update.

Fourthly, local EXAs instruct the operators to perform relevant operations at each step, such as disassembling the assembly parts, removing the obstacles or replacing the fault components, assembling the assembly parts *et al*. Meanwhile, they also monitor the validity of operation at current step and update the information of execution state by interacting with the CVMTS. Then the information is distributed to the related local EVAs for further analysis and evaluation. Fifthly, local EVA in each workstation evaluates that whether the maintenance operation at current step meets the related condition and achieves the maintenance goal or not. And then the local EVA distributes the evaluation information to the central EVA to make the global evaluation for the current operation step of CVM.

Finally, if all the conditions in operator nodes were achieved, the central EVA will send a success message to the central DEA and the central DEA will allocate the

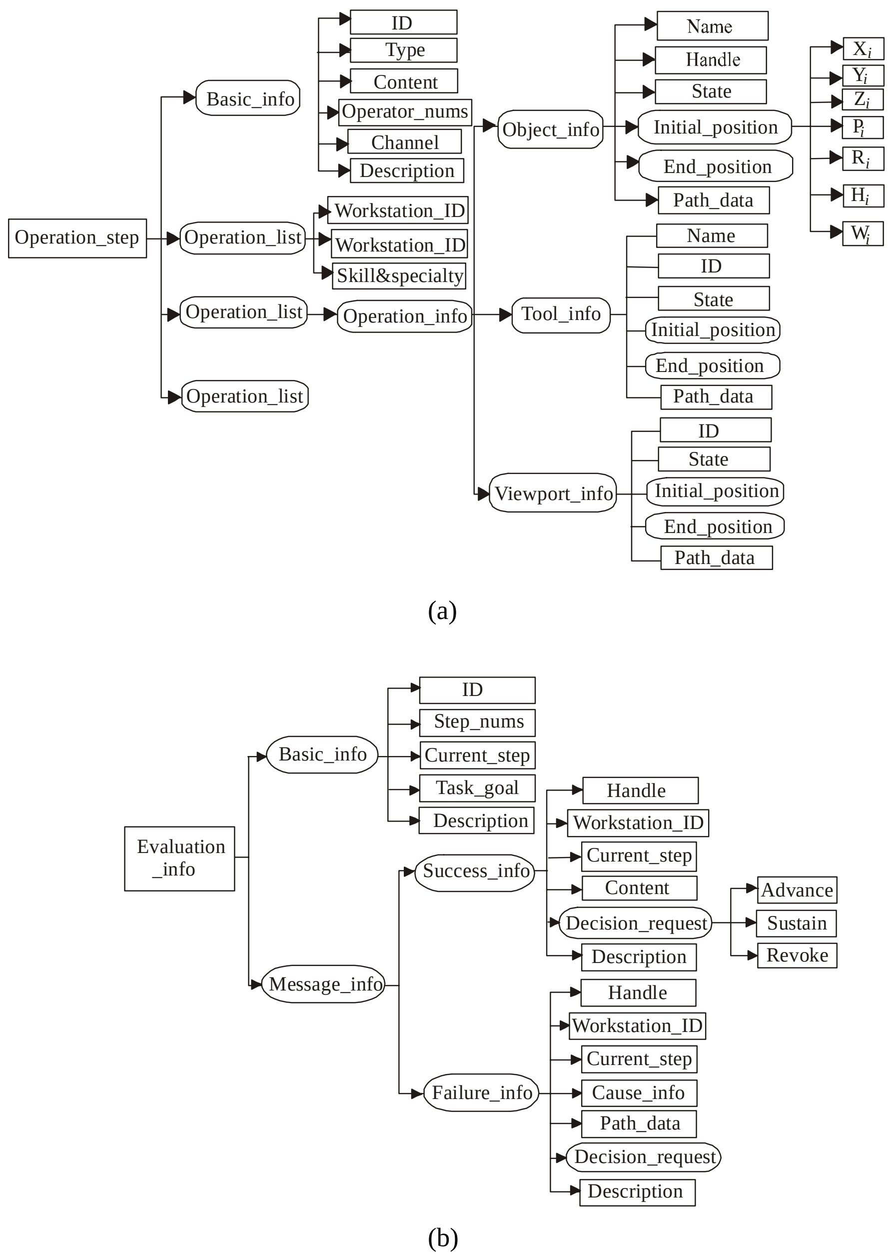

Fig. 8: XML schema structure for maintenance operation steps and evaluation information

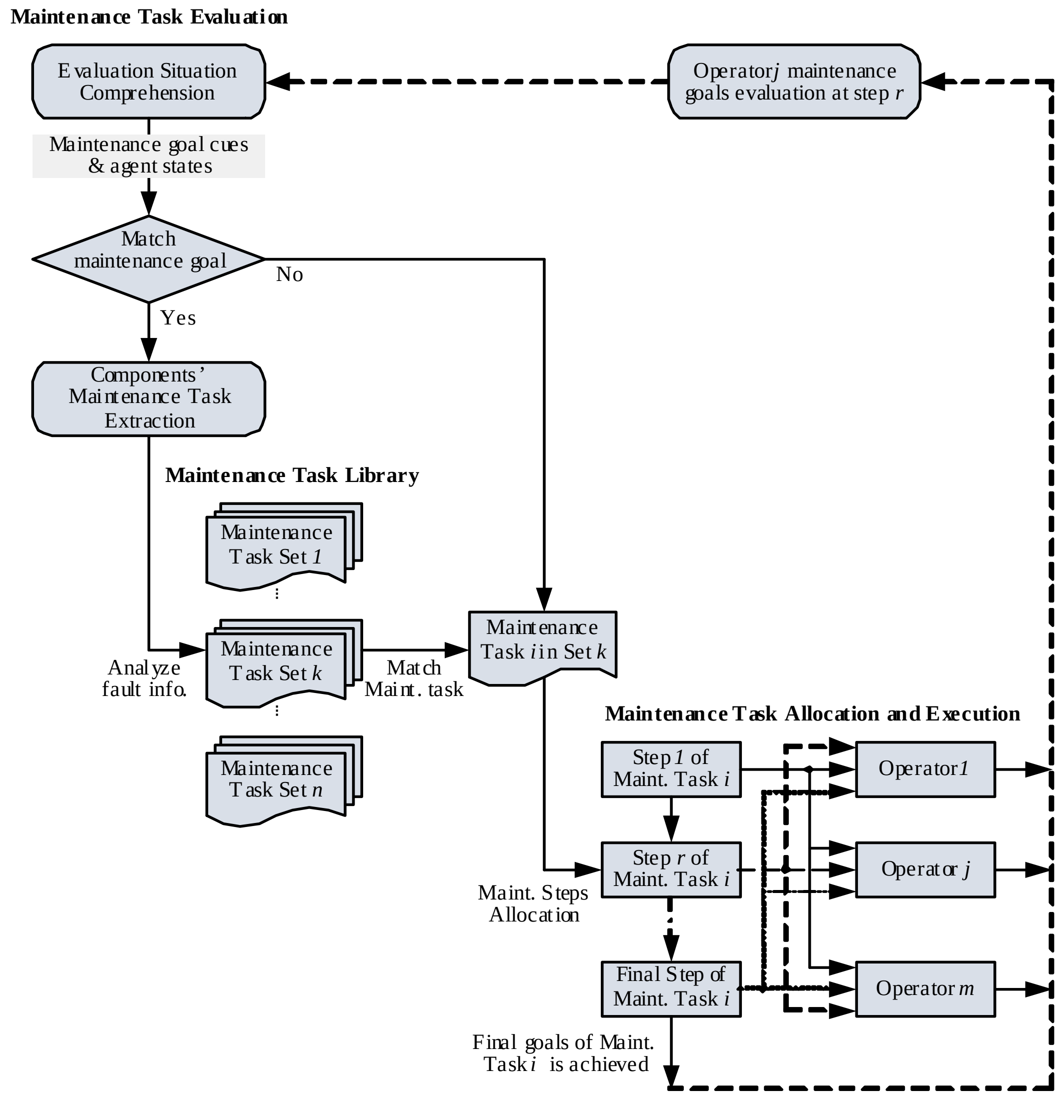

Fig. 9: Workflow of decision making process of collaborative MTA

maintenance task for the next step. Otherwise, the central EVA will send a failure message with the information of execution to the central DEA and it will request the central EXA keep distribute the current task to the local DEAs until all operator nodes finish the allocated task.

Collaboration of the maintenance task allocation: As the CVMTS is established based on HLA/Run-Time Infrastructure (RTI), the Agent communication language KQML and the RTI service are utilized to implement the collaboration of MTA. The key critical factors of the collaboration of MTA are the execution state and corresponding transform of EXAs, such as the change of maintenance operation steps, quantity of remaining components in the assembly structure, assembling state. Then the local EVAs make the evaluation for maintenance operation at current step with the defined maintenance goal and sent the evaluation information to central EVA by the interactive communication.

In order to make the communication information of MTA can be interpreted and implemented by each Agent node. The operation step and evaluation information is represented in XML with the specified document scheme definition. In this way, the various data and information can be contained by the XML file to communicate interactively. The structure of XML OIT for maintenance operation steps and evaluation information are shown in Fig. 8.

As tags in XML follow a hierarchical structure, the necessary information of operation steps and evaluations can be well organized in a single XML file. According to the defined XML scheme, the complex information of a maintenance process can be saved in a single XML file. The file contains the entire data and information to realize maintenance training activity. The path data of operation information as shown in Fig. 8a records the moving path of a component, a tool or the viewpoint, which will be used to generate the operation animation for operator training. The decision_equest of message information as shown in Fig. 8b requests the central DEA for the next processing such as advance, sustain and revoke.

In order to implement the collaboration of MTA, the strategy of collaborative interaction based on MAS and HLA is established according to the function of each AU. The workflow of decision making process of the collaborative MTA is shown in Fig. 9. With the strategy, the MTAM governs each operator node can operate collaboratively and accomplish the maintenance process at each step. And it will allocate new task for other training only when all the previous operation steps and goals are finished and achieved. Therefore, the whole process of collaborative MTA and relevant decision making can be controlled automatically, which ensures the operators can acquire not only the skill of maintenance operation but also the decision making for cooperative work.

EXPERIMENTAL SIMULATION

Based on the techniques and methods mentioned above, together with other key technologies, a prototype system named CVMTS has been designed and developed. The CVMTS provides an integrated platform and immersive virtual environment for complex equipment maintenance teaching and training and is established upon developing environment of Virtual Reality (VR) and VC++/MFC. The system runs on the standard desktop PC with Windows operating system which utilized as management platform with GUI and the single channel passive-stereoscopic projector system with graphic workstation that provides three-Dimensional (3D) vision. And the VR interaction devices are data gloves, space mouse, position tracking equipment and motion capture system, which can convert the operation information of maintenance operators such as hand action, space position and body posture to digital signals for the CVMTS with the API functions under the standardized interface protocol.

A case of large-scale MEH Equipment (MEHE) is used to demonstrate the proposed methods and the fault simulation and MTA for CVM of its subsystem *i* that shown in Fig. 1 is presented in this section. In subsystem *i*, the output flowrate of hydraulic pump is 30L/min, the setting pressure value of relief valve I, II are 20 and 16 MPa, respectively. And there are 4 detection points FS I, PS I, FS II and PS II that named as P_1, P_2, P_3 and P_4, respectively and three executing steps during the work process of this subsystem. As the fault tolerant efficiency R_{ij} are valued as vector R_j = [0.02, 0.02, 0.02, 0.02], according to the values shown in Fig. 4, the parameter ranges and eigen value zones of the detection points can be calculated by (1)~(2) and are listed in Table 1. Considering that P_4 would be influenced by relief valve I when relief valve II is jammed severely, so its maximum value $maxP_{i4}$ is also selected as 20 MPa.

Then the potential fault values ranges of the detection points in subsystem *i* can be calculated by (3)~(4) and are listed in Table 2 in detail.

As shown in Table 3, there are mainly four types of faults in the subsystem and the related fault information

Table 1: Description of parameter information in subsystem I

P_j	PR_j	PEZ_{jk} K = 1	K = 2	K = 3
P_1(L/min)	[0, 30]	[20.79, 21.21]	[12.67, 12.93]	[7.52, 7.68]
P_2(MPa)	[0, 20]	[2.57, 2.63]	[9.11, 9.29]	[15.8, 16.16]
P_3(L/min)	[0, 30]	[20.59, 21.01]	[12.47, 12.73]	[0, 0.09]
P_4(MPa)	[0, 20]	[2.38, 2.42]	[8.91, 9.09]	[15.64, 15.96]

Table 2: Potential fault information of detection points in subsystem I

P_j	FP_{jk} ($LFP_{ijk} \cup HFP_{ijk}$) K = 1	K = 2	K = 3
P_1 (L/min)	[0, 20.79] ∪[21.21, 30]	[0, 12.67] ∪[12.93, 30]	[0, 7.52] ∪[7.68, 30]
P_2(MPa)	[0, 2.57] ∪[2.63, 20]	[0, 9.11] ∪[9.29, 20]	[0, 15.80] ∪[16.16, 20]
P_3 (L/min)	[0, 20.59] ∪[21.01, 30]	[0, 12.47] ∪[12.73, 30]	[0.09, 30]
P_4(MPa)	[0, 2.38] ∪[2.42, 20]	[0, 8.91] ∪[9.09, 20]	[0, 15.64] ∪[15.96, 20]

Table 3: Description of fault information in the proposed subsystem

Fault type	Fault code	Description	Expected output
I	I_{11}	The leakage of pilot valve in relief valve I	[1 0 0 0]
II	I_{21}	The median of three-potential four-way direction valve is fully blocked	[0 1 0 0]
III	I_{32}	The throttling orifice of relief valve II is jammed severely	[0 0 1 0]
IV	I_{42}	The severe inner leakage of multilevel cylinder	[0 0 0 1]

of them is listed in detail. As the fault mode of each component in actual subsystem is relatively changeless, it can be coded as fault code to make the programming of fault simulation more easily. And the fault code includes three parts: the serial number of subsystem, the serial number of components and the code of fault degree. Fault degree includes 3 types: high,mid and low, which are coded as 1, 2 and 3 respectively. For example, I_{11} denotes that the component 1 in the proposed subsystem that marked as i has a severer fault. Then the fault code is calculated by the fault simulation model to set up the fault parameters in the subsystem. And the calculated results are also taken as input samples for the training of fault diagnosis module.

In order to ensure the reliability of fault simulation resut, influence trend of four fault types W_{ijkm} and V_{ijkm} (m = 1, 2, 3, 4) in HFP_{ijk} and LFP_{ijk} are selected through analyzing theoretical fault eigen values and 100 groups of independent simulation results. With defined W_{ijkm} and V_{ijkm}, the fault eigenvalues FPE_{ijk} of P_{ij} in subsystem i at working step k can be calculated by (5)~(6). As there may be faults with components at any working step, 100 random arrays of FP_{jk} at each working steps as listed in Table 2 are selected as fault samples to calculate the fault eigen values FPE_{jk} and train the BP neural network in fault diagnosis module.

Fault type IV is taken as an example to illustrate the MTE and MTA of CVM and the main process is as follows:

Fault type IV is selected with GUI by teacher as the maintenance training task.

The random fault simulation parameters of P_{ij} at different working steps are generated, then FPE_{ijk} of P_{ij} are calculated and inserted into the subsystem i.

According to the current working step, operators select the relevant fault diagnosis model to confirm the fault type and components with the detection values of fault parameters.

As the main causation of fault type IV is that the sealing ring or gasket inside the multilevel cylinder is worn or broken, thereby the maintenance task is defined to replace the sealing ring or gasket inner with a new one. MTAM of CVM allocates the relevant maintenance task to each operator, then multi operators perform the maintenance operation collaboratively to achieve the maintenance goals of components. And their operations at each step will be evaluated with the maintenance goals.

CONCLUSION

Based on the fault injection and diagnosis simulation with simpler fault simulation models, maintenance task of CVM for the complex equipment is established and allocated dynamically to each operator with MTAM through the maintenance operation process of fault parts and components. The XML-based OIT which represents collaborative operation information of multi operators is established to perform the interactive communication of heterogeneous data and information in CVMTS. Finally, a case study is conducted with experimental simulation of subsystem in complex equipment, which has shown that the proposed methods worked effectively in the collaborative maintenance training of complex products.

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