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A STUDY ON CONSTRUCTING A MACHINE-MAINTENANCE TRAINING SYSTEM BASED ON VIRTUAL REARITY TECHNOLOGY

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ABSTRACT

The development of a VR based training system are presented for teaching disassembling procedures of mechanical machines used in nuclear power plant. The methods of Petri net model for describing trainees' plausible actions in the disassembling process and reduce a right sequence of action sequence are developed as well as realization of the related Petri net editor and the demonstration of the developed VR based training system was demonstrated by example practise of disassembly simulation of check valve. Moreover, the needed future works are also discussed.

1.INTRODUCTION

Needless to say, regular maintenance is indispensable in nuclear industry for safety operation of nuclear power plants(NNP). And for reliable practice of the maintenance work, it is very important that the workers should be well trained to meet the required skill level. Therefore today, the training centers for maintenance workers have been established by Japanese nuclear industries and there, a lot of training courses have been in service to the workers, with the guidance of experienced instructors to take care of them, by using many kinds of real-size mockups of machines and equipments used in the nuclear power plant. Such off-the-job training are effective in building up workers' maintenance skill, but it is said to be very costly and time consuming for training many workers. Therefore, new kind of training systems are needed to compensate for the present training methods.

Recently, Virtual Reality (VR) technology has emerged and developed remarkably so that it becomes now possible for us to apply VR technology for various training purpose. In fact, it was reported by NASA that VR-based training had been very successful in on-the-ground pre-training of space shuttle staffs who were in charge of Hubble telescope repairing in outer space[1].

Reflecting those two situations of the present technology, the authors would like to propose a VR based experience-oriented CAI system for plant maintenance training, in order to introduce more freely and flexible learning environment than by current practice of worker training. Here, the words "experience-oriented" means "spontaneous build-up of knowledges and skills through self-experience" with respect to:

1)superior comprehension of structure and functions of machines,
2)superior comprehension of assembling, disassembling and inspecting procedure,
3)superior ability to judge whether the parts of machine are damaged or not, and,
4)superior ability to make trouble shooting (finding machine malfunction and primary cause of failure, and planning proper countermeasure to the situation).

As a primary step toward the proposed system development, the authors have been developing VR based training system for training disassembling procedures of 'check-valve' with the use of Petri net model for describing the related procedure[2]. In this paper, the authors would like to discuss how to extend their currently on-going work towards the system development for realizing such 'experience-oriented CAI'.

2. OVERALL CONFIGURATION OF VR BASED EXPERIENCE-ORIENTED CAI SYSTEM

The whole configuration of the VR based experience-oriented CAI we are in mind can be depicted as shown in Fig. 1. As seen in the figure, the system consists of User Interface, VR-based Simulator, Intelligent Instruction Generator and System Control Block. The major functions of the four parts are briefly summarized as follows;

(1)User Interface

This is the interface between the training system and the trainee as well as for the instructor. The direct input-output devices given to the trainee are basically composed of conventional VR devices such as 3D projection display, crystal eyes, datagloves and polhemus sensors, in order to realize mutual interaction between the system and trainee. Through these devices the trainee can watch virtual objects by 3D graphics and manipulate the object by emulated hands such as grasp, rotate, release, and so on.

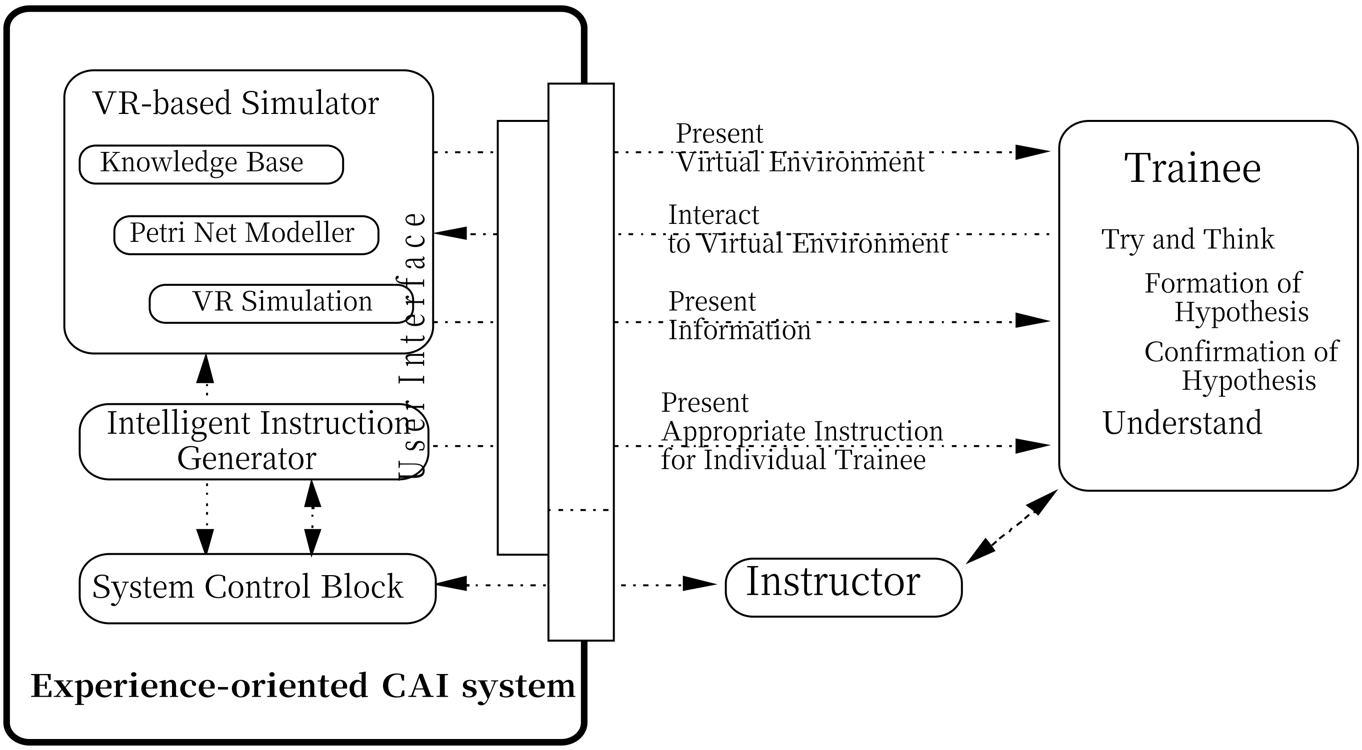

Figure 1 - Configuration of VR based experience-oriented CAI system for maintenance workers.

Moreover, multimedia information such as synthesized sounds, voice, cut- away picture, etc., are also provided to the trainee during the training course, in order to enhance communication reality or to compensate for the lack of haptic feedback, as well as to increase the flexibility of instruction capability. Other interface functions are also provided to the instructor for the purpose of editing and updating the authoring materials to the system and for monitoring and controlling the course of training.

(2)VR-based Simulator

This is composed of knowledge base, Petri Net Modeller and VR simulation handler, in order to produce and manage the whole virtual environment needed for the training. For example, VR Simulator produces 3D dynamic images which matches with the trainee's viewpoint, and the movement of tokens in Petri net model is controlled in accordance to the trainee's action in the VR space by processing the trainee's interaction data sent from User Interface. Various knowledge bases and the related databases will be provided in the simulator for the pre-processing to the trainee's course of action in VR space for the support of Intelligent Instruction Generator.

(3)Intelligent Instruction Generator

This will navigate the training course and generate appropriate critique to the trainee according to the training situations and trainee's level.

(4)System Control Block

This is related with setting of training condition, controlling training sinarios, and recording trainee's data, which will be made by the instructor.

3. TRAINING SCENARIO AND NECESSARY SIMULATION FUNCTIONS FOR TRAINING SYSTEM

At the start of realizing the VR-based experience-oriented training system, the most basic and fundamental simulation functions are summarized as below;

1) The training system can be operated easily and can be understood intuitively,
2) Any trainee can execute variable tasks with his satisfaction,
3) Any trainee can change his view point as he likes,
4) Any trainee can ask to the system as to which should be the next step of execution at any time and situation, and
5) The training system can be applied to any training target and procedure with little workload of system modification.

We think that those requirements for the VR-based training system were already materialized by our past developmental works by the use of virtual reality (refer to our past paper [3].

But in addition to the above requirements, there are more aspects as to the knowledges and skills to be mastered by a trainee to become a specialist of NPP maintenance workers than the above-mentioned aspects of mainly usage convention. Those kinds of knowledges and skills should be implemented in any kinds of training system as the appropriate scenarios of training course. Taking those aspects in mind, we depicted a standard course of training machine maintenance work as shown in Fig. 2. From this figure, we can introduce the following

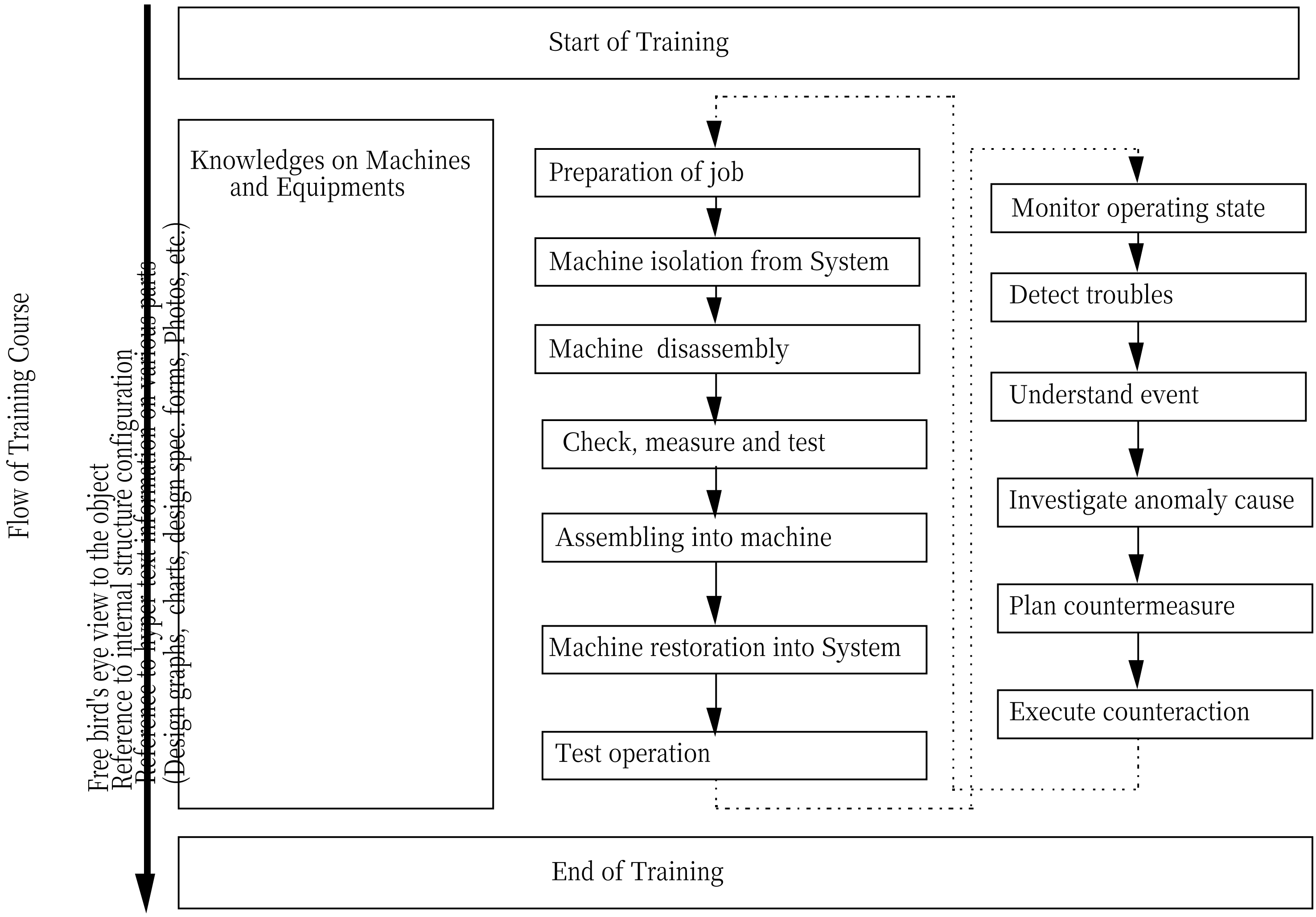

Figure 2 - Training course mastering knowledges and skills for machine maintenance.

three major training scenarios which correspond to the different kinds of needed skills for the maintenance worker.

(1)Scenario 1 for understanding structure and function of machines,
(2)Scenario 2 for mastering appropriate procedures for disassembling, checking and assembling machines, and
(3)Scenario 3 for building up knowledgen on trouble shooting and repairing of machines.

The relationship of those scenarios to the flow of training course in Fig.2, is that the left-hand block in the figure corresponds to Scenario 1, the central flow to Scenario 2, and the right-hand flow to Scenario 3, respectively.

Therefore, in order to implement those scenarios into the training course, it will be necessary to realize the following three different kinds of simulation function in the VR-based simulator:

(1)Simulation of basic physical laws---This is related with realistic description of physical behavior of the virtual object in the virtual space, such as smooth shift of view with the movement of trainee 's body and head, such as realistic free fall, rotation, swing of virtual object according to the fundamental law of mechanical motion, etc.
(2)Simulation of various constraints in the working environment---This corresponds to such judging function that the trainee's tasks and actions applied to the virtual object would be possible or not, on the lights of physical constraints and procedural constraints.
(3)Simulation of troubles in the virtual object---This is the simulation of the machine state due to various trouble phenomena such as leakage from machine, vibration of machine, degradation of parts, etc. Also included in this category is the human-error-caused troubles in the machine caused by the violation of inhibited procedure.

4. APPLICATION OF PETRI NET MODEL FOR VR-BASED SIMULATION

The Petri net model[4] can be applied for the above-mentioned VR-based Simulation in the training system, because it has been widely used for formal description of various phenomena of parallel and discrete state transition type, such as parallel processor, software programming, movie robot control, etc. In the light of three different simulations mentioned in the previous section, we have almost developed the Petri net model with the related softwares for the part of simulation of machine assembly/

disassembly procedure[2], and we are now in consideration of another Petri net model for describing simulation of machine failure mechanism and its propagation.

4.1 Simulation of Machine Assembly/Disassembly Procedure

4.1.1 Petri net model for describing machine assembly/ disassembly procedure

Before going to the development of VR-simulation and the related Petri net model for Machine Assembly/ Disassembly Procedure, we made a detailed task analysis to the disassembling procedure of check valve used in nuclear power plant, by referring the training materials (manual and video tape) used in the maintenance training center of Japanese nuclear industry. Based on the results of task analysis, we made the following basic considerations for the both inter-related developments of VR-simulation and Petri net model for Machine Assembly/Disassembly Procedure:

(1)Classification of trainee's action: Trainee's actions during the training course are classified into the four types;
(i)Normal action--- the same action as the designated as the right action in the manual,
(ii)Inhibited action-- the actions strongly inhibited or warned by manual, although possible to do,
(iii)Possible action--- the actions not specified in the manual, although possible to do, and
(iv)Impossible action--- physically impossible action.

Although those types of (i) and (ii) should be considered in designing the VR-based training system, the setting of the rest types (iii) and (iv) is a difficult problem; if we would like to set the more covering of type (iii), the system should cope with the more versatile situation thus difficult to design, and for the other type (iv), it will be difficult to realize this type ideally, if there are proper feedback from VR space to the trainee.

In those respects, we decided to set the range of type (iii) as wide as possible, and to use alternative mechanisms such as warning sound and visual flushing to compensate for the lack of haptic feedback in our developed system.

(2)Basic concept of representing actions: There are three basic element processes in describing the trainee's plausible actions in the training system;
(i)Description of the state of "Object"--- Here, the meaning of "Object" is the minimum element of target which can no more divided into fine element in the simulation. Therefore, if there are more than two nuts, e.g., used in the assembling, the individual nuts will be treated as different objects.
(ii)Recognition of the meaning of actions based on the movement of hands to various combination of "Objects" in different state. This means, for example, that the recognition of the Object's state "spanner attached on nut" will be realized by the combination of two objects " "spanner hold by hand" approaching to "nut set in the volt".
(iii)Recognition of future actions from the present object's state whether they will be above-mentioned types of (i), (ii), or (iii).

(3)Basic rules of Petri net formation--- The following basic rules specific to the developed system were constructed to describe multiple states of "objects" and their state transition;
(i)One token is assigned to one "Object",
(ii)Different states of "object" plausible in the simulation is represented by "place", or "object place" more strictly in the presented Petri net model, and the realization of that state is represented by the existence of token in the place.
(iii)State change of "object" by the action of trainee is represented by the "firing " of "transition". Therefore, individual basic actions made by trainee correspond to individual "transitions".

(4)Formation of "Job" concept : Here, we call " individual basic tasks comprising a procedure" as "Job". The exact definition is that the "job" is a set of basic tasks operated with a certain objective, and that the initial state is the state that there is nothing to hold in hands while the terminal, again nothing to hold.

Those four kinds of consideration are the basic notions of constructing both the VR-simulation and the related Petri net model. As far as the Petri net model is concerned, we further elaborated the model framework in order to cope with other needed functions for VR-simulation of the assembling/disassembling procedure. The symbols, meanings and the illustrative explanations for our employed Petri net model are all explained in Fig. 3.

4.1.2 Development of Petri net editor and its effect

It is a laborious and time consuming task to construct a whole Petri net by hand, and there, a supporting system was developed to help editing Petri net model on GUI using a Toolkit called Tcl/Tk [5]. The basic functions of this Petri net editor is summarized as below;
(i)Several basic <actions> which use <a certain tool > with <left or right hand > to a <certain object > are prepared in formatted string on CRT to set a sequence of basic task element to describe the related procedure,
(ii)Automatic conversion of the input data of the procedure to graphic representation of Petri net model on CRT, and
(iii)Preparation of database for storing inputdata and its reuse.

With the use of the developed system, the constructive work for Petri net model became much

Conventional Petri Net			Newly Inrtoduced Idea			
Terminology	Symbol	Correspondence in the Example	Terminology	Symbol	Correspondence in the Example	Meaning
Transition			(1)	Automatic Transition	‖	(5)	This transition fires automatically without trainee's actions.
Token	●	(2)	Pool Place	⬭	(6)	Plural tokens are permitted to enter in this place at once
Arc	→	(3)				
Object Place	○	(4)	Control Place	◎	(7)	To control actions of complicated Petri net, represent various conditions for transitions to fire

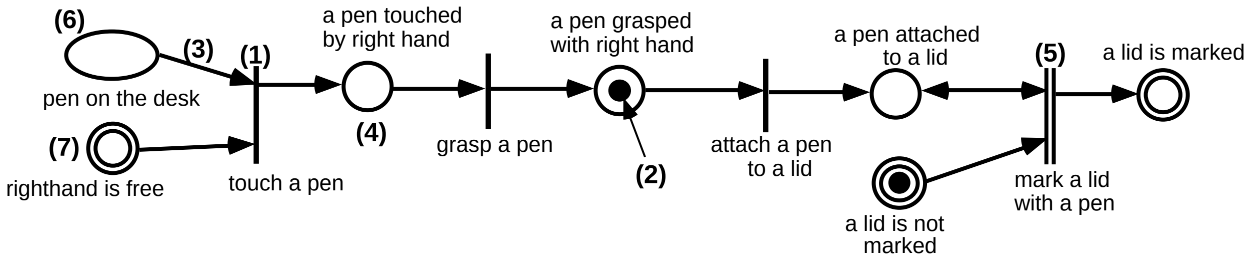

Figure 3 - The notations and example of Petrinet model used for describing machine disassembly procedure.

mitigated in time with avoidance of careless mistake, especially for the construction of the whole procedure model for a different kind of machine which is similar to an already constructed model by the update work of already developed database.

4.1.3 Development of automatic execution mode

The meaning of "automatic execution mode" is a demonstration function in the CAI system to show the trainee what is the right procedure by VR simulation. To realize this mode, it is necessary for the training system to have the information on right procedure other than afore-mentioned function of describing various types of plausible actions made by trainee. Therefore , it is necessary to develop appropriate method for describing the right procedure. The right procedure is defined by the right sequence of jobs, superimposed by the definitions of right sequences of "actions" in each job.

In order to obtain "right procedure", we assumed that the following data are prepared for each of the transitions in the whole Petri net under the premise that execution priority for each "job" is given apriori.

(i)Name of Job within which the transition is included,
(ii)Name of Job which finish by the firing of the transition, and
(iii)Name of the transition to proceed the job and name of Job after the end of the job in case of all the past sequence of tasks satisfies the job priority sequence, or
(iv)Name of transition to reset the job and the name of Job to expire the job in case of other wise.

If those information are apriori, then it becomes possible to judge whether right action or not, and determine the right action to do, for each action to be made by trainee. Although it is rather difficult to discuss the detail of the method within the scope of this paper, the critical point of the adopted method is that the given information mentioned in the last paragraph will designate what is the right sequence of transition firing, and what is the right sequence of job to do disassembling successfully.

The left issues to be discussed are how to reduce optimum search algorithm of fast running capability.

4.1.4 Demonstration of the developed system

The concepts and methods mentioned in this section were applied for a pilot VR-based simulator for training disassembly procedure of check valve. The pilot simulator was constituted by two graphic workstations, one for VR simulation control by Indigo2, and the other for management of Petri net model, connected with each other by socket communication. Figure 4 is a scene of the training process of disassembling the valve, watching 3D

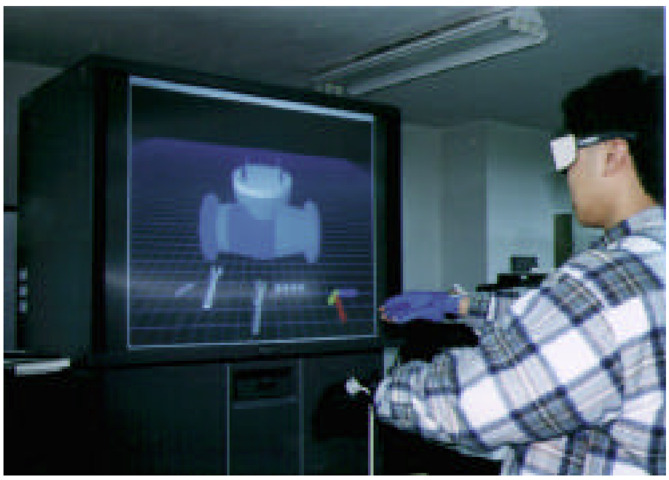

Figure 4 - A scene of practising disassembly of check valve by the developed VR based trainig system.

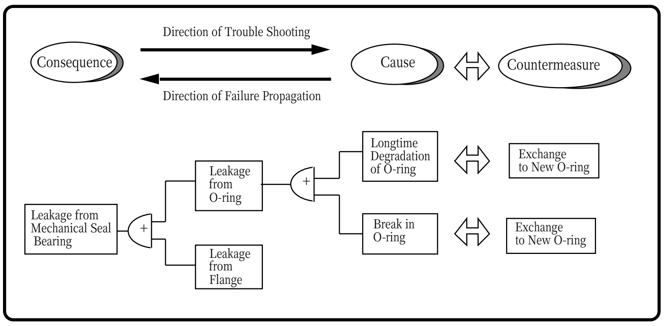

Figure 5 - An example of FT which illustrates cause-consequence relationship in failure propagation.

projection display through the stereo glass and manipulating the object by datagloves of both hands.

4.2 Simulation of Machine Failure Mechanism and its Propagation

At present, we have not proceeded to the development of this topic of modeling machine failure mechanism and its propagation by using Petri net model. In fact, as far as we know, the current practice of treating the problem is that the analysis of various disturbances caused by either human error during maintenance or the inevitable degradation or plausible damages of various parts in the long time service has been made by FMEA(Failure Mode and Effect Analysis), and the comprehensive representation of the logical propagation of the cause consequence relationship have been made by FT(Fault Tree). The example of such FT is shown in Fig. 5, where direction of the failure propagation is given by three-layered logic gates from the root cause of right-hand side until the top event of left-hand side. On the other hand of failure propagation, trouble shooting is made by the reversed direction from the top event down to the root cause. If the root cause is identified, then appropriate counter measure will be applied for the failed part of the machine. This is essential point of trainee's mastering trouble shooting skill.

Although the FT technique is effective tool for describing failure mechanism of machine and the failure propagation from the root cause until the top failure event, it will be rather inconvenient to use it in the integrated training system we are in mind. The reason is that since there will be a lot of disturbances to be considered in the system, there would be more FTs prepared. Moreover, the FT method is fundamentally a static model, thus it is difficult to describe the time-dependent, parallel and discrete event transition of the failure mechanism in concern. In this respect, the Petri net model is, in principle, more effective and convenient than the counterpart. But there will be a new idea needed for applying the Petri net for the present purpose in the following points;

(1)Consideration of interaction of Procedure simulator by way of human- error-caused troubles in the machine,

(2)Consideration of time effect of ranging from very short time effects up to very long time effects which will be far beyond the span of training time but perhaps to be educated,

(3)Consideration of various damaged configuration of the various parts and equipment and their effects both in VR-simulation and procedural Petri net model and the dynamic simulation of damaged state of the machine by physical law.

5. CONCLUTION

In this paper, the authors presented the method of using Petri net model for developing a VR based training system for teaching disassembling procedure of check valve. The further works will be needed for the present system, and they are (i)the extension of the present Petri net model to consider the hierarchical organization, (ii)development of efficient algorisms for reducing right procedure sequence for the larger size Petri net than present with the automatic method of related database construction, and so on. Afterwards, we would like to proceed to a difficult but interesting topic of constructing Petri net model for the simulation of failure mechanism of machine and its propagation.

ACKNOWLEDGMENTS

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