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The virtual simulation system for training and demonstrating the design of the head-end of spent nuclear fuel reprocessing

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ABSTRACT

This paper is meant to develop a virtual simulation system for training workers and dynamically demonstrating designs of the head-end of spent nuclear fuel reprocessing. This paper suggests the requirements of the system and describes the system's hardware and software. The system was developed in a virtual simulation environment. The performance test proved that the system is appropriate for training workers and demonstrating the designs of reprocessing plants.

1. Introduction

Workers involved in spent nuclear fuel reprocessing need to be familiar with working environments in which workers use remote handling systems to operate, because the environment is closed and highly radioactive during repairs and maintenance. On-the-job training for repairs and maintenance works could effectively train workers, but this training approach could be costly and trainees are not allowed to modify any equipment or improve designs during the training. Therefore, a virtual training system could be much more efficient than a physical training system (Jeong et al., 2014; Freitas et al., 2014). A virtual simulation system could also dynamically demonstrate some process systems, evaluate and optimize related designs (Jeong et al., 2016).

This paper is intended to develop a virtual simulation system that can train workers and help designers optimize the reprocessing systems. It describes the requirements of the virtual simulation system and the system's hardware and software designs. The system was developed on the basis of a visual virtual simulation scene that can be modified with ease.

2. Requirements of the simulation system for spent nuclear fuel reprocessing

Table 1 presents the requirements of the virtual simulation system. These required items are (1) simulating how to operate equipment, (2) demonstrating and optimizing the reprocessing procedures in the systems, (3) inspection of personnel and logistics channels, (4) aiding the development and test of preliminary repair and maintenance procedures, and (5) related primary operator training.

Simulating how to operate equipment is the basis of development for the virtual simulation system, and operating equipment and factory buildings form the main part of the process system simulation. Demonstrating and optimizing the rationality of the reprocessing procedures in the systems are that designers and experts evaluate the system according to dynamic visual simulation scenarios and give some suggestions for optimization and improvement. Inspection of personnel and logistics channels is that designers navigate the personnel and logistics channels in first-person mode and find defects in the designs. Aiding the development and test of preliminary repair and maintenance procedures means that designers can design and dynamically visualize the procedures with the aid of the simulation program developer. Of course, the final virtual simulation system can be used to train the workers who need to operate many kinds of manipulators, cranes, and linkage equipment in the future plant.

3. Configuration of the virtual simulation system

3.1. Configuration of the simulation system

Based on the requirements of the system as suggested in Table 1, the hardware and software of the system were selected as shown in Table 2. The hardware system includes a large back-projection

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Table 1
Requirements of the virtual simulation system.

Items	Descriptions
Simulating how to operate equipment	The basic component of the virtual simulation system of the head-end of a spent nuclear fuel reprocessing pant
Demonstrating and optimizing the rationality of reprocessing procedures in the systems	Evaluation, optimization, and improvement of the reprocessing systems according to dynamic visual simulation scenarios
Inspection of personnel and logistics channels	Finding defects in the designs of the reprocessing systems by navigating simulation scenarios in first-person mode
Aiding the development and test of preliminary repair and maintenance procedures	Designs and visualization of the procedures with the aid of simulation program developer
Related primary operator training	Training the workers who need to operate many kinds of manipulators, cranes, and linkage equipment in the future plant

Table 2
Configuration of the virtual simulation system.

Items	Descriptions
Hardware	A large back-projection stereoscopic display system A graphic server Two 24-inch LCDs Three joysticks A control panel A touchscreen display Some 3D shutter glasses
Software	3D Via Studio Visual Studio

stereoscopic display system, two LCDs, three joysticks, a control panel, and a graphic server. The development of simulation software is based on 3D Via Studio and Visual Studio.

The connecting relationship of the system hardware is shown in Fig. 1.

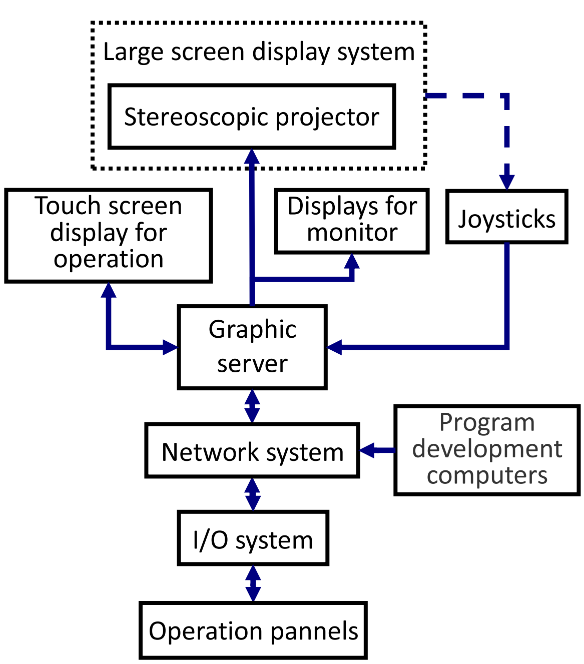

Fig. 1. Hardware topology of the virtual simulation system.

The 3D Via Studio is a development tool with graphical script language that enables plant building and equipment scenarios to be simulated and evaluated. The data and subprogram management interface are based on C# in Visual Studio. The communication codes between the graphic server and control panel are programed based on socket.

3.2. Configuration of function modules for the virtual simulation system

To efficiently handle and manage the virtual simulation system, the function was modularized as seen in Fig. 2. The interface can manage all function modules of the virtual simulation system, but it is also the secondary interface of the software system. The modules indicated by the purple, blue, and green colors achieve the automatic demonstrations of the system's technological process and the running process of the main equipment. Through these modules, the designers and workers can comprehend the dynamic systems and equipment. The modules indicated by the red color achieve the interactive operations of the tool devices used for maintaining all the equipment in the hot cell. By the modules, designers can optimize the repair and maintenance procedures and workers can be trained to be familiar with the operational methods and process.

4. Development of the virtual simulation system

4.1. Hardware development of the virtual simulation system

Development of the system includes two parts: hardware and software.

The hardware development is the design, installation, and test of the system hardware according to the functional requirement and room conditions in which the system is installed. The design result is shown in Fig. 3. The back-projection system and control panel were designed and manufactured based on the functional requirement. The room size is the constraining condition for the system. As for the graphic station, projector, joystick, display, data acquisition card, and others, we adopted commercial products.

The large back-projection stereoscopic display system was used to present a stereoscopic picture to operators wearing 3D shutter glasses who used the simulation system, which simulated the inspection windows of the hot cells of the reprocessing plant. The graphic server was the core system hardware in which all simulation and communication programs ran. The two LCDs were used to simulate the monitors that were fixed on the wall of the hot cells and displayed those images from the cameras installed in the hot cells. Three joysticks were used to simulate the operations of the master-slave manipulators, which were installed through the walls of the hot cell and applied to remotely operate the tools and equipment that needed maintenance or repair in a radioactive environment, because a joystick has more buttons than other computer input devices. The control panel, which was based on the actual equipment, was linked to the graphic server through some data acquisition hardware and communication programs for operators to feel as though they were actually operating the equipment. The touchscreen display had been fairly commonly utilized in industry as an interface to realize display and control, so it was also used to simulate the interface to control the equipment in the hot cell. The design of the virtual operation interfaces referred to the actual control panels, which were intended to verify the feasibility of using touchscreens as a control device.

The panels are the workplace for the system users, and the workbench in the back row is the workplace for coaches, simulation system developers, and designers. In general, in order to sim-