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Development of a VR-based Experienceable Education System -A Cyber World of Virtual Operator in Virtual Control Room -

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ABSTRACT

A VR-based experienceable education system has been developed by realizing human-shaped virtual operator in virtual control room of Nuclear Power Plant (NPP). The virtual operator has expertise knowledge about NPP on how to diagnose some anomalies and operate the control panels by himself. The human-like body motion of the virtual operator can be generated as 3 dimensional (3-d) animations. With this education system, a trainee can watch the virtual operator operating the control panels from any view-direction the trainee would like to see. And he can also 'experience' the plant operation by viewing the control room from the virtual operator's viewpoint as if the trainee would operate the control panels by himself. Moreover, the trainee can understand what the virtual operator thinks, by hearing the verbal utterance of the virtual operator. With this education system, it is expected that the trainee can master the skills for operating the control panels effectively. The overall architecture of the developed education system and the functional configuration of the system are described in this paper.

Keywords: Virtual Reality, Human Motion, Education System, Nuclear Power Plant, Computer Animation

1. INTRODUCTION

The subject of this study is how the VR-based cyber world will be effectively applied for the education and training of operator trainee of NPP. To speak something beforehand about the real practice of NPP operator training in Japan, a large amount of expertise and enough experience are of course necessary for a plant operator to become well expertised as to diagnose a plant anomaly and manage the plant state safely, in the event of emergency situation of NPP. And it is very difficult for a novice to master all the relevant skills for operating the control panels of NPP in a short time. To master these skills sufficiently, it is necessary for the novice operators to have many hours of class room teaching in the daytime and personal learning by using PC-based CAI even in the free time. This build-up education period lasts for some months before going to the advance course at a training center where a real-size mock-up and a plant simulator are used for training operators to give them expertised skills of normal operation as well as accident operation. It takes a lot of time and cost for them to build up as well expertised operator. Therefore the low-cost education system is required with which a trainee can master expertised skills effectively in a short time.

One of the effective learning methods is showing the trainees videos to illustrate how the skilled operators operate the control panels. This teaching method of using videos would be more effective than lessons using text and transparency pictures, but there are some drawbacks as below to produce videos for training purpose:

- To make a training video, it is necessary for an actor to operate control panels or real-size mock-ups in front of video cameras. But it takes a lot of time and cost,
- If the design of the control panel to be mastered is changed (for example, the location of an instrument is changed) the videos must be revised for the changed part, after video production,
- Even toward the same anomaly, there are plural procedures to be conceived. It is desirable for a trainee to see the operation for all procedures.

But it takes a lot of time and cost to make videos for all procedures,
- A trainee cannot change the viewpoint to watch the control panels, and
- Even if a trainee want to know the state of the nuclear power plant, for example "How high the pressurizer level is now?", it is impossible for the trainee to examine it.

Therefore, a more economical, flexible AV-based teaching than by conventional video is requested for the operator training. In this study, a VR-based experienceable education system has been developed to meet above-stated requirement. In this system a nuclear power plant simulator which can simulate some plant anomalies is used and a virtual control room is developed in a virtual space. And a human-shaped virtual operator who has expertise knowledge about NPP and plant anomalies is realized. He can collect the information about the state of the nuclear power plant simulator by walking in the virtual control room by himself and he operates the control panels. This is a new education system with which a trainee can watch the virtual operator operating the control panels from any viewpoint the trainee would like to see. Especially, a trainee can view the virtual control room from the virtual operator's viewpoint and the trainee can 'experience' the plant operation as if the trainee would operate the control panels by himself. Moreover, the trainee can understand what the virtual operator thinks by hearing what the virtual operator speaks. With this education system, it is expected that the trainee can master the skills for operating the control panels effectively.

This experienceable education system has many advantages than the learning method viewing the training videos:

- Because the control panels are made in a virtual control room, it is not necessary to make a real-size mockup of control panels. So this education system is very economical. And it is easy to make a function for a trainee to walk through in the virtual control room. Moreover the design of the virtual control room can be changed easily by changing the database of the virtual control room.
- By changing the database of the virtual operator's knowledge, it is possible for the virtual operator to act differently for the operation of control panels in accordance with the different plausible procedures even if the plant anomaly is the same.
- Because a nuclear power plant simulator is executed as a part of the experienceable education system, the timing of plant anomaly occurrence can be changed freely. And a trainee can refer the calculation results of the nuclear power plant simulator to understand its state.

From the next chapter, the configuration of the developed education system is described.

2. OVERALL ARCHITECTURE OF THE EXPERIENCEABLE EDUCATION SYSTEM

The experienceable education system is designed as a distributed simulation system, to make it possible for us to use the experienceable education system with low-performance and economical computers. The overall architecture of the experienceable education system is described, with respect to both the software and hardware configurations.

Software configuration

As shown in Figure 1, the experienceable education system consists of the Simulation Based Evaluation Support System for Man-Machine Interface Design (SEAMAID) and the other four simulators: Human Body Motion Simulator, Speech Synthesis Process, Monitor Simulation Process and Virtual Space Drawing Process.

The SEAMAID system has been developed together with Mitsubishi Electric Corporation. The SEAMAID has been originally developed as the evaluation system for the design of the control panels in NPP, and it consists of three simulators: Nuclear Power Plant Simulator, Man-Machine Interface Simulator, and Human Model Simulator. The Nuclear Power Plant Simulator is a real time dynamic simulator of an actual PWR plant, which can simulate various kinds of plant anomalies. The Man-Machine Interface (MMI) Simulator is based on an on-line object-oriented database model for the MMI design information of the plant control room. And the MMI design information database includes the information about layout, shape, location, panel, etc. of various equipment in the control room, and the MMI simulator is connected to the plant simulator to update the contents of the temporal behavior of instruments on MMI. The Human Model Simulator realizes 'intelligent functions' of the virtual operator, by employing a general human model framework which was proposed fundamentally based on human memory model from cognitive psychology[1]. The Human Model Simulator has an ability to diagnose an anomaly of NPP and has knowledge about the standard operation procedure on where to go, what to check and how to judge in accordance to the operation manual. For the further details of the SEAMAID, please refer our published paper[2].

The Human Body Motion Simulator generates the

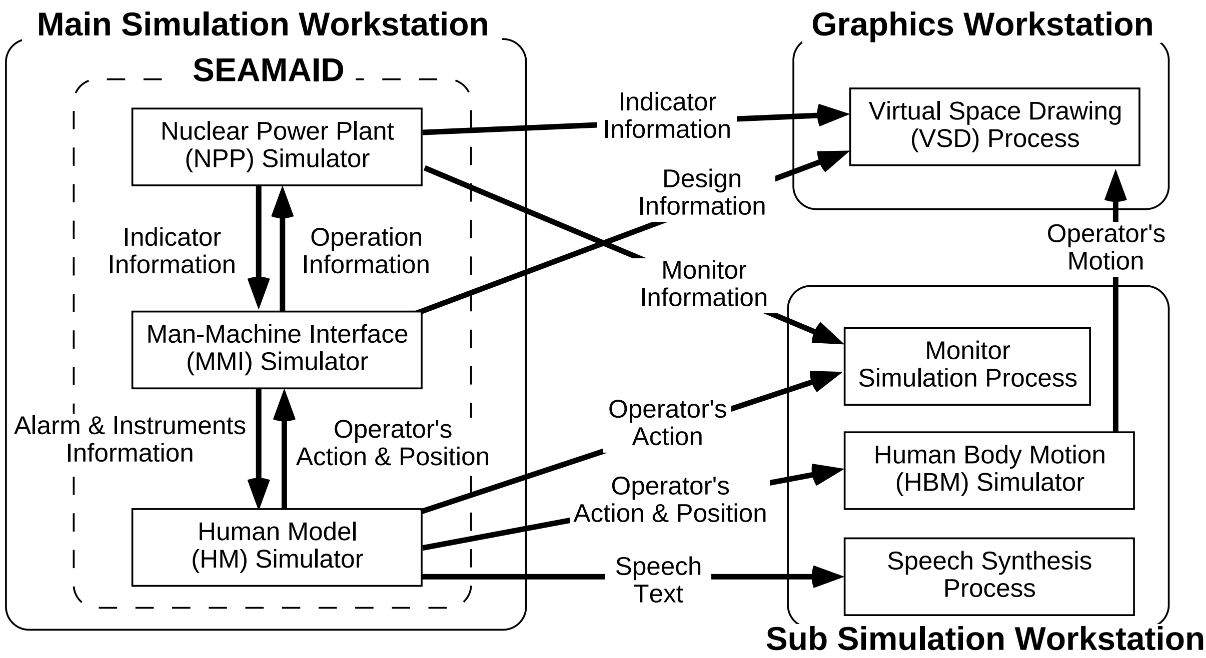

Figure 1: Overall Architecture of the experienceable education system.

human-like motion of the virtual operator operating the virtual control panels by using the information about virtual operator's action and position obtained from the Human Model Simulator and sends the virtual operator's motion sequence to the Virtual Space Drawing Process. The Virtual Space Drawing Process manages a virtual environment in real time, where not only the body motion of the virtual operator but also the various conditions of control room itself is visualized. The Speech Synthesis Process synthesizes the virtual operator's speech such as "I will check the pressurizer level.", "I think the leak of coolant accident has occurred." and so on, to express the virtual operator's thinking process. The Monitor Simulation Process generates 2 dimensional (2-d) images of CRT display monitor, which is one of the instruments located on the virtual control panels, and displays the detail information of the Nuclear Power Plant Simulator. The details of these four simulators are described in the next chapter.

Hardware Configuration

The experienceable education system consists of three workstations (Main, Sub and Graphics), a 3-d mouse and a CrystalEyes. The 3-d mouse will be used for changing the trainee's viewpoint, while the CrystalEyes is for viewing the stereo graphics. The SEAMAID is executed on the Main Workstation. And the Human Body Motion Simulator, the Monitor Simulation Process and the Speech Synthesis Process are executed on the Sub Workstation. The Virtual Space Drawing Process is executed on the Graphics Workstation. And these workstations are connected via network, and the necessary information is transmitted by the socket communication method.

By this way, the experienceable education system has been developed as a Distributed Simulation System. The advantages of this design approach are summarized as follows:

- The computation load to simulate a virtual control room can be distributed to some rather low-performance computers.
- Plural environment can be provided for plural trainee to watch the virtual environment at the same time if introducing more sets of 'Graphics Workstation' into the established education system, to execute Virtual Drawing Process on them in parallel. So, for example, it is possible that one trainee experiences the operation of control panels while the other trainees watch the same virtual environment from the different viewpoint.
- It is also possible to introduce more sets of 'Sub Simulation Workstation' to execute different Human Body Motion Simulators on them.

3. THE CONFIGURATION OF THE FUNCTIONS THE EXPERIENCEABLE EDUCATION SYSTEM PROVIDES

Synthesis of the virtual operator's motion

Basically, the virtual operator's motion is synthesized by using the motion database, which is obtained by measuring a real human's motion. The underlying procedure is as follows: First the actual human body motions of "walk" and "operation" are measured by a 3-d motion capturing system, and then basic motion database is built by the measured data. When generating the body motion, the appropriate basic motion is selected from the database, and modified to fit the objective motion. By this method, the walk motion of arbitrary direction and distance, and the operation motion of pushing buttons and sliding levers can be generated naturally in real time. The details of how to measure the actual human body motion and how to compose them were described in our paper [3]. With this synthesis method, the virtual operator's motion can be synthesized at rates of 20-30 Hz on a 150MHz SGI workstation.

Drawing the virtual control room

From the Nuclear Power Plant Simulator, the Virtual Space Drawing Process receives the information about the current state of the nuclear power plant. And the indication of the instruments located on the virtual control panels is updated in real time. So the trainee can watch the current state of the nuclear power plant through the virtual instruments located on the virtual control panels.

The realized 'virtual control room' in the experienceable education system consists of 10 control panels on which about 500 instruments are installed. To decrease the computational time for drawing the virtual environment, the method of LOD (Level Of Detail) is applied so that the level of details is changed in accordance to the distance between the trainee's position and each instrument. For example, if the distance is long, only the outline of the instrument is drawn, while if the distance is short, the instrument is drawn with their details. Figure 2 shows a snapshot of the virtual control room realized in a virtual space. With this artifice, the computation time for updating the images of the virtual control room can be reduced, but the rate for updating is about 5 Hz (closest to a control panel) and 40 Hz (far from any control panels). To make it possible for a trainee to use the experienceable education system without any discomfort, the rate should be more than 20 Hz. Of course, it is possible to increase the drawing ability by using the more high-performance computer with the sacrifice of inevitable high cost. It is necessary to improve the algorism to draw the virtual control room as a future work.

Synthesizing the virtual operator's speech

There are two methods, a visual method and an auditory method, to communicate the cognition from the virtual operator to the trainee. In this study, to increase the "presence" (the sense of being present) of the virtual operator and make it possible for a trainee to merge into the virtual environment, an auditory method is applied. The virtual operator speaks at the these limited situations:

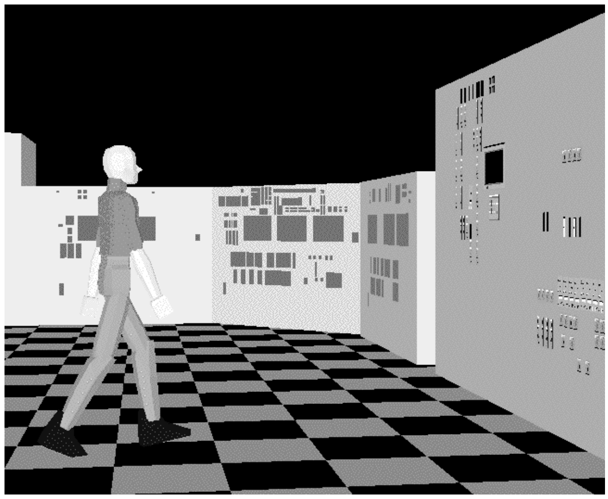

Figure 2: A snapshot of the virtual control room.

- When the virtual operator has assumed that a plant anomaly has occurred, he will speak, for example, "I think a primary leak has occurred."
- When the virtual operator decides to check a parameter, he will speak, for example, "I will check the pressurizer level."
- When the virtual operator confirms what kind of anomalies has occurred, he will speak, for example, "I have confirmed a primary leak has occurred."
- When the virtual operator has checked the value of a parameter, he will speak, for example, "I think the pressurizer level is higher than before", and
- Report, when an alarm occurs, for example, "I recognized a process monitor alarm has been on."

The Human Model Simulator has a focal working memory (FWM). This memory has the information about the current thinking process of the virtual operator. Therefore, by abstracting the information from the FWM, the content of the virtual operator's cognition can be known in real time. Actually, from the Human Model Simulator the contents of the virtual operator's cognition is send to the Speech Synthesis Process. And the Speech Synthesis Process plays the appropriate audio files which was recorded previously. The audio files can be divided into some categories: noun, verb, adjective and the other. And when the virtual operator speaks, some audio files are played in series. With this artifice, the number of the audio files to be prepared can be reduced. In this education system, the total number of the prepared audio files

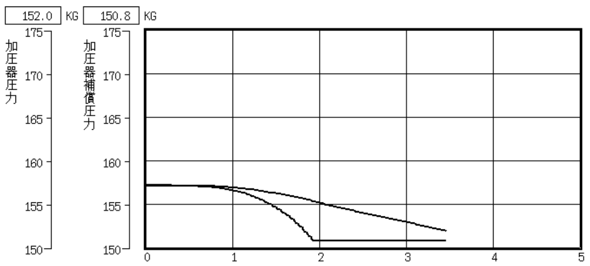

Figure 3: An example of a trend graph.

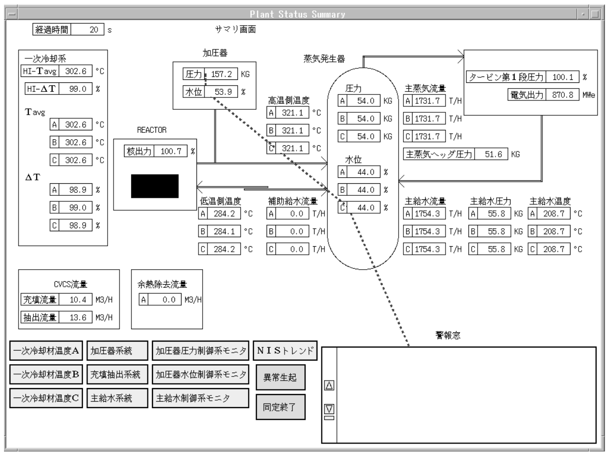

Figure 4: An example of the 2-d image a CRT monitor displays.

for simulating the anomaly 'leak of coolant accident' amounts to 52 files.

Drawing the 2D image for a CRT monitor

A CRT monitor, which is one of the instruments located on the control panels, displays the detail information of the nuclear power plant. And a trend-graph as shown in Figure 3 is sometimes displayed on it. A trend-graph is important for an operator to understand how the state of the power plant changes. But if such a graph is drawn on the CRT monitor correctly in virtual environment, the computation load will considerably increase.

Therefore, in the experienceable education system, besides a main display for viewing 3-d computer graphics of the virtual control room, a second display special for viewing 2-d images of the CRT monitor is prepared. And the Monitor Simulation Process receives the information about which CRT monitor the virtual operator views from the Human Model Simulator, and the information of the nuclear power plant from the Nuclear Power Plant Simulator. Then the Monitor Simulation Process displays the image of the CRT monitor as shown in Figure 4 on the second display in accordance to the virtual operator's action in real time.

Moreover, to make it possible for a trainee to understand where the virtual operator look at on the image of the CRT monitor, an arrow with its trajectory is indicates on CRT display which shows the parameter referenced by the virtual operator, in accordance to the virtual operator's operation action.

By using these new functions, the trainee can recognize both of the actions and thought of the virtual operator at the same time. Therefore, the trainee can understand why the virtual operator does such actions through the VR-based experienceable education system.

Generating the image from the virtual operator's viewpoint

It is also possible to use a Head Mounted Display (HMD) to provide a stereo-view function with this education system. But as described before, it is necessary for a trainee to see the 2-d images for a CRT monitor. So, in this education system, a CrystalEyes is utilized as 3-d viewing device.

The sight images of the virtual operator's viewpoint should be synthesized based on the direction that the virtual operator's head faces as well as the distance between the virtual operator and the control panel. In this education system, the orientation of the operator's head is decided as follows:

- When the operator stands just in front of the panel and is going to turn to the instrument that the operator intends to check next, the operator's head would gradually change from the former instrument to the next instrument. In this case, the trainee will see the sight images of control panel sliding gradually in accordance to the operator's head turning towards the target instrument.
- When the operator is walking towards the next target instrument, it is assumed that the operator looks straight to the target instrument while walking. In this case, the trainee will see the sight images zoom up, that is, the target instrument becomes larger and larger as the operator approaches to the target instrument.

With this function, the trainee can experience the action for operating the control panels with reality, as if he would become a 'virtual operator' to do plant operation in virtual control room. Figure 5 shows an example of the image from the virtual operator's viewpoint.

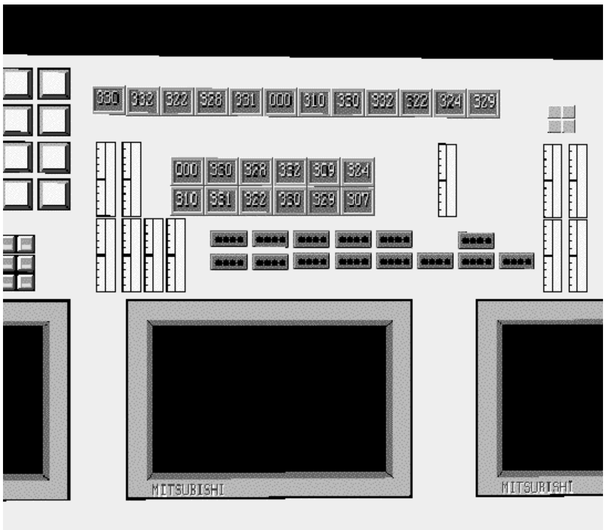

Figure 5: An example of the image from the virtual operator's viewpoint.

4. SYSTEM VALIDATION

Several students were asked to examine the developed system to show them two example simulations: LOCA (Leak of Coolant Accident) and SGTR (Steam Generator Tube Rupture). The impressions stated by them were as follows:

- Using the experience function, I can feel the sense that as if I would walk in the control room.
- It is interesting to use the experience function.
- I could understand what the virtual operator thinks.
- I feel sick after a long time use.

It is very important that the opinion 'It is interesting to use the experience function.' could be obtained, because it means that the experienceable education system can attract the trainee's interest. So the experienceable education system can make the trainee continue to learn the plant operations.

On the other hand, it is a serious problem that there was the opinion that a long-time use of 3-d animation made him sick. The physiological influence of VR should be an issue to investigate further to prevent or mitigate it, for the real introduction of this sort of training system.

5. FUTURE WORKS

To make it possible to apply the experienceable education system to the actual training, the function will be required that a trainee can operate the virtual control panels by himself through some devices special for VR. But it may be difficult for a trainee to operate the virtual control panel in 3-d virtual world, if the adopted devices are not easy to use. It is also very important to select a user-friendly device for the experienceable education system.

At the present status, the anomalies which the developed education system can simulate are only LOCA and SGTR. But there are many plant anomalies for a trainee to master the skills for diagnosing and operating. To use the experienceable education system at the training center actually, it seems necessary that the experienceable education system can simulate at least a several kinds of plant anomalies. One of the future works is to construct the database for simulating the other plant anomalies.

6. CONCLUSIONS

In this study a VR-based experienceable education system was developed with which a trainee can watch the virtual operator operating the control panels from any viewpoint the trainee would like to see. The whole configuration of the VR-based Experienceable Education System and the developed function of the system are summarized in this paper. The authors believe that this sort of cyber world of virtual operator in virtual control room would give the trainees an effective training environment with less cost and less time than by the present practice in the NPP operator training center.

7. ACKNOWLEDGMENTS

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