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A Basic Study on Virtual Collaborator as an Innovative Human-Machine Interface in Distributed Virtual Environment: — The Prototype System and Its Implication for Industrial Application —

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ABSTRACT

The objective of this study is to develop "Virtual Collaborator" as a new type of human-machine interface, which works as "intelligent interface agent" to help machine operators manipulating large scale machine system such as power plants. The Virtual Collaborator is a sort of "virtual robot" which behaves as if an intelligent agent robot in virtual reality space, who can communicate naturally with human like humans do with each other. As for the first stage of the virtual collaborator development, a prototype system has been constructed. While the prototype system has no communication function with humans, it can behave just like a plant operator in the simulated control room of nuclear power plant in virtual reality space. And the intelligent capabilities being implemented into the present prototype system are: (i)anomaly detection and root cause diagnosis by checking instrumentation status, and (ii)counter-operation to cope with plant emergency in accordance to the emergency response manual. The animation of operator behavior is visualized on the large projection display, and the presented virtual operator can verbalize what is in 'his mind', and explain what he is thinking. Although the current prototype system has no bi-directional communication capability with human, it can be applied to some industrial fields.

1 INTRODUCTION

Recently due to the increased automation by the introduction of modern computer and information technologies, the machine systems have become so large and complex that the operation of the machine systems has become more difficult task for users. Especially, in the field of aircraft and power plants, the tendency is conspicuous and an operation error may cause serious accidents. Therefore, the study on the man-machine interface has been extensively made to improve the relationship between human and the machine system.

The main theme of this study is the pursuit of "What is an ideal man-machine interface for large scale system?". Humans have evolved for thousands years and have had various abilities. Highly advanced intelligence and communication ability are some of them. However, it can not be said that humans have enough operation ability of large and complex machine systems which have been developed since sores of years ago. The authors pay attention to a communication ability with humans each other which humans originally have, and try to realize of an ideal man-machine interface by an agent robot as an avatar of machine system, which behaves and communicates with humans like humans do.

In this study, the agent robot is named "virtual collaborator", which is realized in virtual reality space. It has human-shaped body and can listen, talk, think, behave and collaborate with real humans in operating large and complex machine systems.

Although the authors have not completed developing the whole system of the virtual collaborator, a prototype system was made up as the first stage of the development, in which the virtual collaborator can behave just like a plant operator in the simulated control room of a nuclear power plant(NPP) in virtual reality space.

In this paper, the basic concept of the virtual collaborator, the configuration of the prototype system and an example of the experimental simulation of the system are described.

2 CONFIGURATION OF VIRTUAL COLLABORATOR

In order to develop the virtual collaborator who can naturally communicate with human, the authors have contrived the configuration of the system as shown in Figure 1. The virtual collaborator has sensing system, thinking mechanism and effector system like humans have. With the sensing system, he can recognize not only the status of machine system but also the actions of human such as motion, speech, gesture and facial expression. With the thinking mechanism, he under-

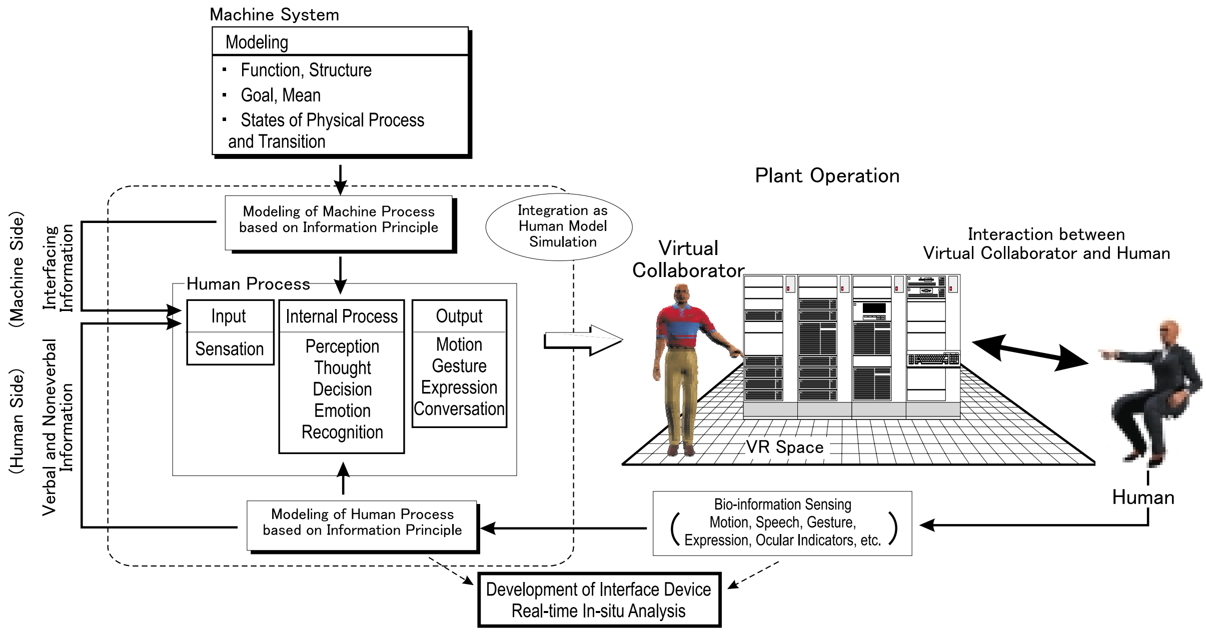

Figure 1: Overall configuration of virtual collaborator system

stands the situation around him and makes decisions. And with the effector system, he can not only help operation of machine system but speak, make gesture and sometimes express his emotion to the human.

In this study, the authors have studied and developed key technologies to realize such virtual collaborator. They are summarized as follows;

1. **Human model simulation** — This is the technology to realize the intelligence of the virtual collaborator by computer simulation. It includes mental model of cognition and emotion, and is capable of treating bi-directional communication between human and the virtual collaborator.

2. **Bio-informatic sensing** — This is the technology to estimate internal states of real human such as thinking process, mental stress and emotion. In order to estimate the internal states, the targets of bio-informatic sensing are not only speech, gesture and facial expression but also various psychophysiological indices such as the distribution of skin temperature, the transition of the heart rate, gazepoint eye-blink, and pupil size.

3. **Bi-directional human interface devices** — This is the technology to realize a new interface device as a physical contact point between human and the virtual collaborator system. In order to realize mutual communication, the devices should provide not only presentation function of 3D visual space as output channel but also sensing function of human actions as input channel by low invasive methods. In parallel with this study, we have developed a new head mounted display called Eye-sensing HMD, which can measure gaze-point, eye-blink, and pupil diameter by real-time image processing.

4. **Synthesis of human motion** — This is the technology to synthesize the body motion and facial expression of the virtual collaborator as natural as possible.

5. **Construction of virtual environment** — The virtual collaborator and its peripheries such as virtual control room should be realized in virtual environment. In this virtual environment, experiments of interaction between human and the virtual collaborator are conducted. This is the technology how to construct such virtual environment efficiently.

The authors have been developing such virtual collaborator system by three stages. The first stage is to construct a prototype system as an integration of the above 1.4.5. technologies. The second stage is to construct the whole system which includes bio-informatic sensing and interface devices to realize bi-directional communication function. The third stage is expansion into 'multi-virtual collaborator system'. The multi-virtual collaborator system is a virtual society realized by Distributed Virtual Environment(DVE), where humans and virtual collaborators communicate with each other in shared virtual environment by using network-connected computers.

In this paper, as the first integration, the prototype virtual collaborator who can behave just like a plant operator in the control room of a NPP has been developed. At present, this prototype system has no

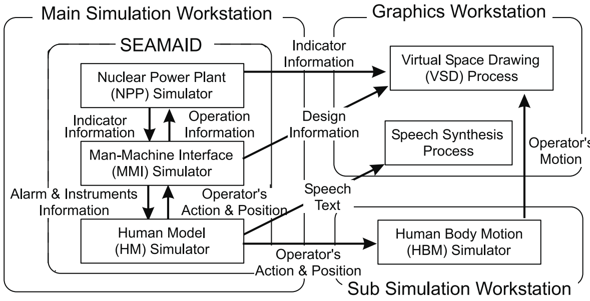

Figure 2: Configuration of prototype system

communication function with human, so that the capability of the prototype system for industrial application in rather limited than that of second stage in order to apply it to industrial fields. That is to say, as its thinking mechanism, the authors aim at realizing not interpersonal communication but simulation of thinking process of real human operator. Concretely, when an anomaly occurs in a NPP, the virtual collaborator can detect it, diagnose the root cause and operate the control panel in accordance with an emergency response operation manual. In each step, he behaves as if he were a real plant operator. It means that the virtual collaborator does not acts as a perfect operator but he can simulate individual variations, occasional variations, human uncertainties, human errors. Thus, the prototype system itself can be applied to examine the behavior of human operator by computer simulation with visualization by 3D virtual space. For example, it can be applied to the simulation of man-machine system interacting at control room and computer-aided experienceable training system for plant operators, and so on.

3 SYSTEM ARCHITECTURE OF PROTOTYPE SYSTEM

In this section, the configuration of the prototype virtual collaborator is described. As shown in Figure 2, the whole prototype system is constructed as a distributed simulation system which consists of the following five subsystems: (1)Nuclear Power Plant Simulator, (2)Man-Machine Interface Simulator, (3)Human Model Simulator, and (4)Human Body Motion Simulator, and (5)Virtual Space Drawing Process. The detail of the subsystems are explained below.

(1) Nuclear Power Plant Simulator
The Nuclear Power Plant Simulator (NPP Simulator) is a real-time dynamic simulator of an actual PWR plant, which can simulate various kinds of plant anomalies.

(2) Man-Machine Interface Simulator
The Man-Machine Interface Simulator (MMI Simulator) is based on an online object-oriented database model to the presented man-machine interface design in the plant control room as 2D images. And the MMI design information database includes the information about layout, shape, location, panel, etc. of various equipment in the control room, and the temporal behavior of instruments.

(3) Human Model Simulator
The Human Model Simulator (HM Simulator) realizes 'intelligent functions' of the virtual collaborator. As mentioned before, the objective of the HM Simulator is to simulate thinking process of a real plant operator, the authors employed a general human model framework[2] which consists of sensory process, focal working memory (FWM), peripheral working memory (PWM), knowledge database, database search process, FWM process and anomaly diagnosis engine. Based on the above components, the virtual collaborator checks the control panel, detects an anomaly, diagnoses the root cause by examining hypotheses, and performs appropriate response operations. In each step, the human model simulator drives Human Body Motion Simulator in order to visualize the motion of the virtual collaborator in the virtual control room. The details of the HM Simulator will be described in the next section.

(4) Human Body Motion Simulator
The Human Body Motion Simulator (HBM Simulator) generates the body motion of the virtual collaborator. In order to realize the naturalness of the body motion, the actual human body motions of "walk" and "operation" were measured by a 3D motion capturing system, and basic motion database was built by the various measured motion data beforehand. When generating the body motion, 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 generate them were described in the authors' papar[1].

(5) Virtual Space Drawing Process
The Virtual Space Drawing Process (VSD Process) generates the virtual space in real time, where various conditions of control panel, the control room and the shape of the virtual collaborator are visualized. The control room consists of 10 control panels on which about 500 instruments are located. If all of the instruction are drawn with 3D polygons, the drawing load becomes too large to draw them in real time. Therefore, Level Of Detail(LOD) method was employed to reduce the drawing load.

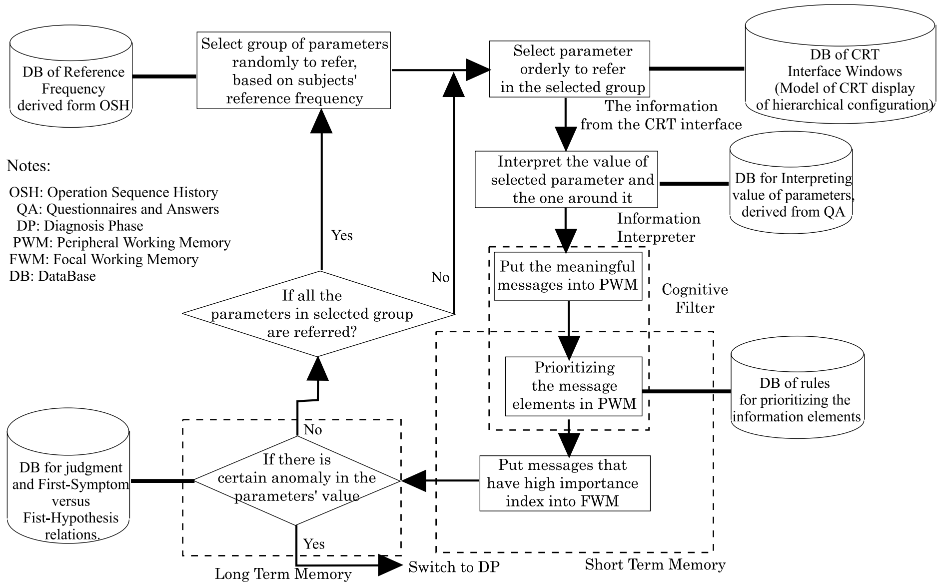

Figure 3: Information processing model in detecting phase

The subsystems (1),(2) and (3) were integrated as Simulation Based Evaluation Support System for Man-Machine Interface Design (SEAMAID)[3].

4 HUMAN MODEL SIMULATOR

The HM Simulator was constructed by using a real-time object-oriented expert system, G2 (GenSym Co.Ltd.)[4]. According to the two phases of detecting and diagnosing plant anomaly, the HM Simulator also consists of two phases. The submodels and processes in each phase are described in subsections below.

4.1 Modeling of detecting phase

In the detecting phase, the HM Simulator checks the values of plant parameters to find whether some abnormal transients occur. Based on the general human model framework, perception, interpretation and judgement are main cognitive processes in the detecting phase. Therefore, three submodels were constructed to perform these three functions.

The perception submodel was made in two steps to perform the perception function. First, main plant parameters are divided into five groups based on main plant subsystems. Human model selects one of the five parameter groups to be checked stochastically. Then in the selected parameter group, parameters were checked in sequence.

The interpretation submodel is to translate the value of parameters into a meaningful message. Here fuzzy logic estimation was applied in order to realize individual variations.

Finally, by judgement submodel, whether there are certain abnormal symptoms and which subsystem of plant seemed to be in abnormal state are decided. If there are no any abnormal symptoms then the next parameter will be checked or the next parameter group will be selected. While, when some abnormal symptoms are noticed, the subsystem of plant which needs to be diagnosed will be passed to the model of diagnosing phase.

Based on such submodels, the modeling of detecting phase is configured as shown in Figure 3.

4.2 Modeling diagnosing phase

In diagnosing phase, besides the perception, interpretation and judgement, operators have to formulate hypotheses, to verify the hypotheses and to make a final decision about what kind of abnormal transient had taken place. Therefore, the modeling of diagnosing phase is more complicated. To model such complicated cognitive processing, working memory element (WME, as shown in Table 1) is introduced to model the information elements in short term memory (STM) processing, and the operators' knowledge and experience about diagnosing abnormal transients which are represented as knowledge database in long term memory (LTM) are modeled as a network structure database. Based on such submodels of STM and LTM, the cognitive processing in diagnosing phase is also modeled in accordance with the general human model framework.

There are various experiences and various kinds of knowledge stored in LTM. The storage formation in LTM can be considered that it is formulated in a sort of network structure, so that the relationships, processing procedures of such knowledge and experiences are stored systemically. To search such vast network database, there are two ways: similarity matching and frequency gambling. Here the authors focus on the latter one and model such network database and fre-

Table 1: Data structure of WME

Item	Explanation
Number	Serial Number of WME
Category	alarm, hypothesis, value prediction, trend prediction, valu state, trend state, loop-decision, diagnosing result
Content	defined according the category of WME
Processing State	Yes or No or reserved or verifying
Priority	The number from 0 to 2
Impression Index	initial value = 7, if "processing state"=yes, then minus 1 per seccond

quency gambling searching way to simulate uncertainties of human operator.

As for the modeling of the vast network database, we only consider operators' experiences and knowledge about diagnosing abnormal transients and divide them in two groups: the knowledge about the control systems of NPP, and the experiences or knowledge about accidents in NPP. If all of the knowledge are represented in one network database, it will become too huge and complex. Therefore the database is divided into modules which are units of knowledge about the control systems and plant behaviors in accidents.

Thus, combined with WME and the model of knowledge network database, the cognitive information processing in diagnosing phase is modeled as shown in Figure 4. In PWM processing, four tasks are performed; (i)making WME based on various information coming from external world through sensing organ as well as internally from LTM, (ii)setting the processing priority of WME, (iii)transferring WME to FWM, and (iv)changing the impression index of WME. In the FWM processing, the tasks are performed based on the category of WME. As for the LTM processing, the main task is to search the database according to the keywords. Such task includes searching the parameters to be checked next, searching hypothesis to be verified, searching rules to change confidence score of hypothesis, and so on.

Such submodels and cognitive information processing procedures construct the whole human model of detecting and diagnosing phase when a certain abnormal transient occurs. For more details, refer to the papers[5, 6].

5 EXAMPLE OF SIMULATION

By using the integrated prototype system, some example simulations were conducted. Here, as an example, the process of simulation is described in the cases that LOCA(Leak of Coolant Accident) occurs in a NPP.

First, Figure 5 shows snapshots of the virtual control room and the motion of the virtual collaborator. As shown in the figure, (a)the control room, (b)the instruments on the control panels and (3)the motion of the virtual collaborator were visualized in real time.

Figure 6 shows the top view of the virtual control

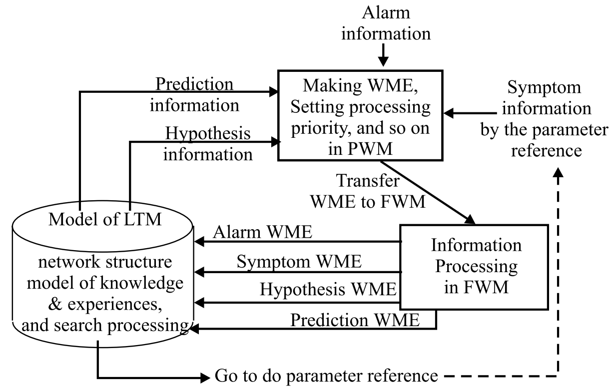

Figure 4: Information processing model in diagnosing phase

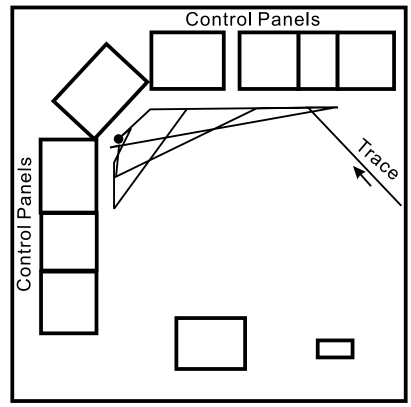

Figure 6: Trace of virtual collaborator

room, in which the trace of the virtual collaborator's walk is indicated when he detected and diagnosed the plant LOCA. As shown in the figure, he walked around the control panels and checked and operated some instruments.

In order to examine his detail behaviors, Table 2 shows some of his operational sequence history. Compared with the results of laboratory experiments which had been conducted by real expert operators who were asked to detect and diagnose the plant LOCA by NPP simulator, it was confirmed that the operation time and patterns were similar. However, all of the operations was not the same because of the behavior variation of human operator and frequency gambling effect of the human model.

6 CONCLUSION

In this study, the authors proposed the concept of virtual collaborator and its configuration as a new type of man-machine interface, and methods of research approaches were described in this paper. Although the whole system is still under development, the authors have developed the prototype system as the first stage accomplishment.

By conducting experimental simulations of the pro-

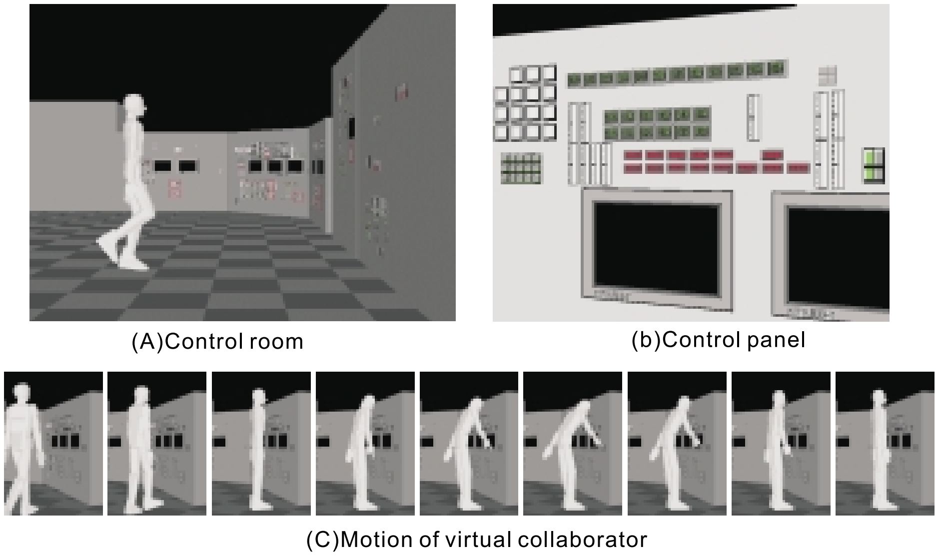

Figure 5: Snapshots of experimental simulation

Table 2: Operation history of detecting and diagnosing LOCA

Time	Behavior (Event)
00:00	(Simulation Start)
00:08	Notices the anomaly by a process monitor alarm
00:08	Suspects primary leak
00:24	Recognizes a alarm that BU heater is ON
00:34	Confirms primary leak occurred
00:34	Suspects LOCA
00:48	Confirms LOCA occurred
00:50	Starts counter-operation of pressurizer level & pressure
....	....
....	....
02:26	Finishes the maintain operation
02:27	Starts emergency load down operation
04:38	Finishes emergency load down operation
05:00	(Automatically reactor tripped)

totype system, it was confirmed that the virtual collaborator behaved as if he was a plant operator in the virtual control room in real time when some plant anomalies occurred in the plant.

As for the foreseen industrial application of this prototype system, it would be useful for the man-machine system design improvement from human factors aspect, such as design evaluation of control room and plant operating procedure when an anomaly occurs in the plant, and computer aided training system for plant operators.

At present, the authors are planning to develop the functions to estimate human internal states and to communicate with real human in order to realize the second stage.

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REFERENCES

[1] H.Shimoda, et al., "A Computer-Aided Sensing and Design Methodology for the Simulation of Natural Human Body Motion and Facial Expression", Proc. of EDA'98, (CD-ROM),1998.

[2] H.Yoshikawa, K.Furuta, "Human Modeling in Nuclear Engineering", Journal of Atomic Energy Society Japan, Vol.36, No.4, pp.268-278, 1998(in Japanese).

[3] H.Yoshikawa, et al., "Development of an Analysis Support System for Man-Machine System Design Information", Control Engineering Practice, Vol.5, No.3, pp.417-425, 1997.

[4] G2 Reference Manual Version 4.0, GenSym Co.Ltd., 1995.

[5] W.Wu, H.Yoshikawa, "Study on Developing a Computerized Model of Human Cognitive Behaviors in Monitoring and Diagnosing Plant Transients", Proc. of IEEE-SMC'98, pp.1121-1126, 1998.

[6] W.Wu, T.Nakagawa, H.Yoshikawa, "Application of Human Model Simulation to Deduce Human Error Probability Parameter for PSA/HRA Practice", Proc. of International Topical Meeting on Safety of Operating Reactors, pp.79-86, 1998.