Virtual Operator in Virtual Control Room: The Prototype System Implementation

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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 controlling large scale machine system such as power plants. In this paper, first, the basic concept of the virtual collaborator is introduced. And, the prototype system of the virtual collaborator is described. At present, the prototype system has no communication function, however, when an anomaly occurs in a virtual nuclear power plant, the virtual collaborator can detect it, diagnose the root cause, and operate the control panel in accordance with emergency operation procedures, autonomously. Then, in order to realise bi-directional communication as the next step, the framework of "Affective Interface" is introduced. The affective interface is a human machine interface system, which deals with "Affective Information" to realise smooth communication between human and machine.

Keywords: Virtual Reality, Human Model, Nuclear Power Plant, Affective Interface

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 operational error may cause a serious accident. Therefore, the study on the man-machine interface has been extensively made to improve the relationship between human and the machine systems.

The main theme of this study is the pursuit of "What is an ideal man-machine interface for large scale system?". The authors pay attention to a communication ability with humans each other which humans originally have, and try to realise 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 realised 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.

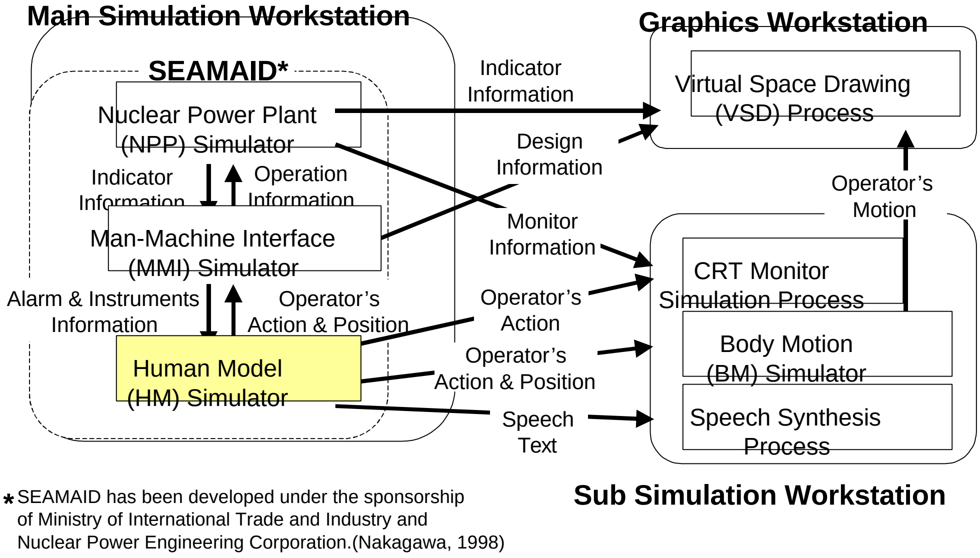

Figure 1 Configuration of Prototype System

In this paper, the configuration of the prototype system, a human model simulator as its intelligent function, an example of the experimental simulation of the system, and the future works toward realising bi-directional communication are described.

Prototype System

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 bi-directional communication function with human, although it can verbalise what it is going to do. The present capability of the prototype virtual collaborator is that, when an anomaly occurs in a virtual NPP, the virtual collaborator can detect it, diagnose the root cause of the anomaly by checking the instrument signals on the control panels, and then manage the plant condition to the safety shutdown state. This is like an ideal skilled operator, but the prototype system may behave as if he were a real plant operator who has "fallible" nature. 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. In addition, his behaviour is visualised in 3D virtual space and his thinking process is verbalised by synthesised voice.

System Configuration

In this section, the configuration of the prototype virtual collaborator is described. As shown in Figure 1, the whole prototype system is constructed as a distributed real-time simulation system which consists of the following five important 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 details of the five 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 behaviour of instruments.

(3) Human Model Simulator

The Human Model Simulator (HM Simulator) realises 'intelligent functions' of the virtual collaborator. The objective of the HM Simulator is to simulate thinking process of a real plant operator. 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 realise the naturalness of the body motion, the actual human body motions of "walk" and "operation" were measured by a 3D motion capturing system, and a basic motion database was built by the various measured motion data beforehand. 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(Shimoda, 1998).

(5) Virtual Space Drawing Process

The Virtual Space Drawing Process (VSD Process) generates the virtual space in real time, where various conditions of control panels, the control room and the shape of the virtual collaborator are visualised. 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.

Human Model Simulator(Yoshikawa,1997, Wu,1998)

The HM Simulator was constructed by using a real-time object-oriented expert system, G2 (GenSym Co.Ltd.). 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 the sections below.

Modelling of detecting phase

In the detecting phase, the HM Simulator checks the values of plant parameters to find whether some abnormal transients occur or not. 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. The model selects one of the five parameter groups to be checked stochastically. Then in the selected parameter group, parameters were checked in a certain order.

The interpretation submodel is to translate the value of parameters into a meaningful message. Here fuzzy logic estimation was applied in order to realise 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 symptom, 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 modelling of detecting phase is configured as shown in Figure 2.

Figure 2 Information processing model in detecting phase

Modeling diagnosis 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 modelling of diagnosing phase is more complicated. To model such complicated cognitive processing, working memory element (WME, as shown in Table 1) was 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 modelled as a network structure database. Based on such submodels of STM and LTM, the cognitive processing in diagnosing phase is also modelled in accordance with the general human model framework.

Table 1 Data structure of WME

Item	Explanation
Number	Serial Number of WME
Category	alarm, hypothesis, value prediction, trend prediction, value state, trend state, loop-decision, diagnosing result
Content	defined according to 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 second

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 frequency gambling searching way to simulate uncertainties of human operator.

As for the modelling of the vast network database, the authors 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 behaviours in accidents.

Thus, combined with WME and the model of knowledge network database, the cognitive information processing in diagnosing phase is modelled as shown in Figure 3.

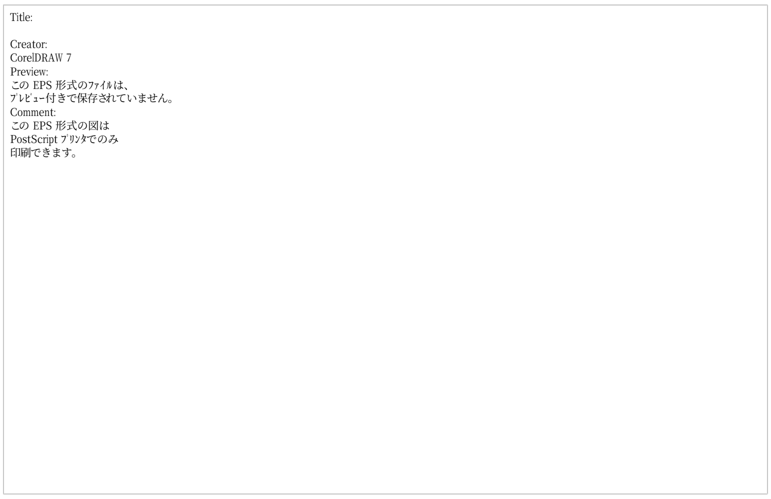

Figure 3 Information processing model in diagnosis phase

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.

Example 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 virtual NPP. First, Figure 4 shows snapshots of the virtual control room and the motion of the virtual collaborator. As shown in Figure 4, (a)the control room, (b)the instruments on the control panels and (c)the motion of the virtual collaborator were visualised in real time.

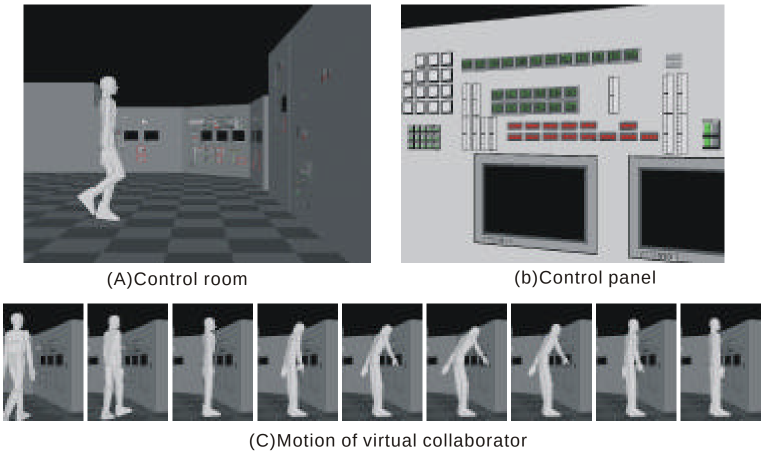

Figure 4 Snapshots of Virtual Control Room and Motion of Virtual Collaborator

In order to examine his detailed behaviours, Table 2 shows some of his thinking process 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 patterns were fundamentally similar action, although all of the operations was not the same because of the behaviour variation of human operator and frequency gambling effect of the human model.

Table 2 Thinking process of human model simulator

Time	Thinking process
00 ‘ 00	*(LOCA occurs)*
:	:
00 ' 39	Checked PRZ Pressure, Detected
00 ' 45	Suspected PRZ Controller Fail High
00 ' 49	Watched Trend of PRZ Pressure
00 ' 57	Watched Trend of Compensation Prs
01 ' 02	Checked Proportion Heater
01 ' 06	Checked Backup Heater A1 & A2 Rejected PRZ Controller Pressure, Suspected LOCA
01 ' 19	Watched Trend of CV-Gas-Monitor
01 ' 25	Watched Trend of CV-Dust-Monitor
:	:
02 ' 55	Checked PRZ Level
02 ' 59	Checked CVCS IN Controller Valve
03 ' 13	Concluded that the LOCA Occurred

Industrial Application of Prototype System

At the present stage of the prototype system development, it has no bi-directional communication function with human, but it can be utilised as follows by its audio-video information visualising functions in 3D virtual space.

- The effectiveness evaluation method of the whole man-machine system designing, and
- The economical training system for instructing the trainee how to operate the man-machine interface comprehensively.

Toward Realising Bi-directional Communication

In order to realise bi-directional communication function, the authors have been studying elemental technologies based on a concept of "Affective Interface". The affective interface is a new concept of human-machine interface, which deals with "Affective Information" in order to realise smooth communication between human and machine. Figure 5 shows the framework of the affective interface. There are two streams of affective information between human and the collaborator. From human to the collaborator, visible signals and invisible signals which are shown at the bottom of the figure, are measured, recognised their patterns, and then the human emotions are estimated. On the contrary, from the collaborator to human, the emotions of the collaborator are generated by a strategy of emotion generation to realise effective collaboration, synthesised their pattern as visible signals, and then the patterns are presented to human. At present, the authors have been studying the following subjects related to the affective interface;

- Emotion estimation from dynamic images of human facial expression by utilising real-time image processing(Shimoda,1999),
- Estimation of arousal level and judgement confidence from biological indices(Sasai, 1999),
- Thinking process estimation from verbal information, operational sequence, and eye-gaze point(Aotake,1999, Ozawa,1999).
- Real-time facial expression generation of the virtual collaborator to express his emotion(Yang,1999), and
- Real-time synthesis of gestures and various motions of the virtual collaborator (Ichiguchi,1999).

The authors are planning to integrate the elementary technologies developed by the above subjects as the next step system integration. Figure 6 shows the future image of virtual collaborator based affective interface system. In the system, the experimental studies will be conducted to realise bi-directional communication function.

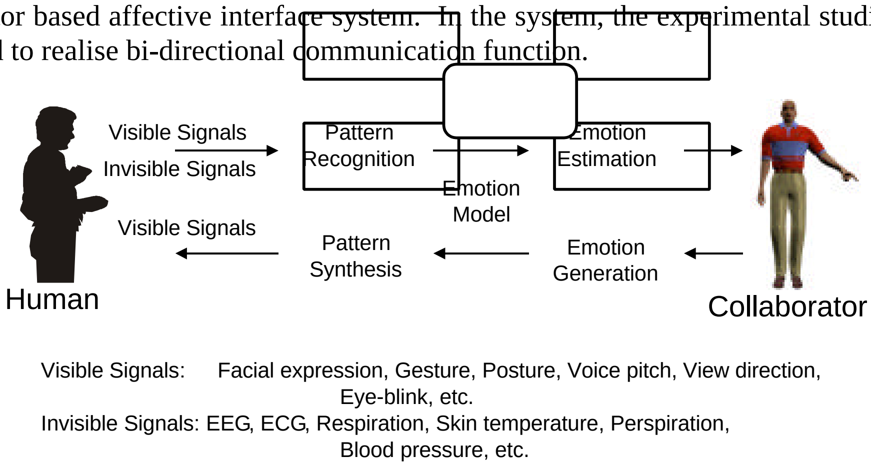

Figure 5 Framework of affective interface

Conclusion

In this paper, the basic concept of the virtual collaborator was introduced, then the configuration of the prototype system was described based on the triple dynamics. At present, this prototype system has no bi-directional communication function with human, however, when an anomaly occurs in a virtual NPP, the virtual collaborator can detect it, diagnose the root cause and operate the control panel in accordance with emergency operation procedures. In order to realise bi-directional communication between human and the virtual collaborator, the framework of "Affective Interface" was introduced. And last, the experimental environment of the affective interface system based on the virtual collaborator was explained as the future work. In the future, the authors are planning to conduct the experimental studies based on the affective interface system and to show its possibility of realising smooth communication between human and machine system.

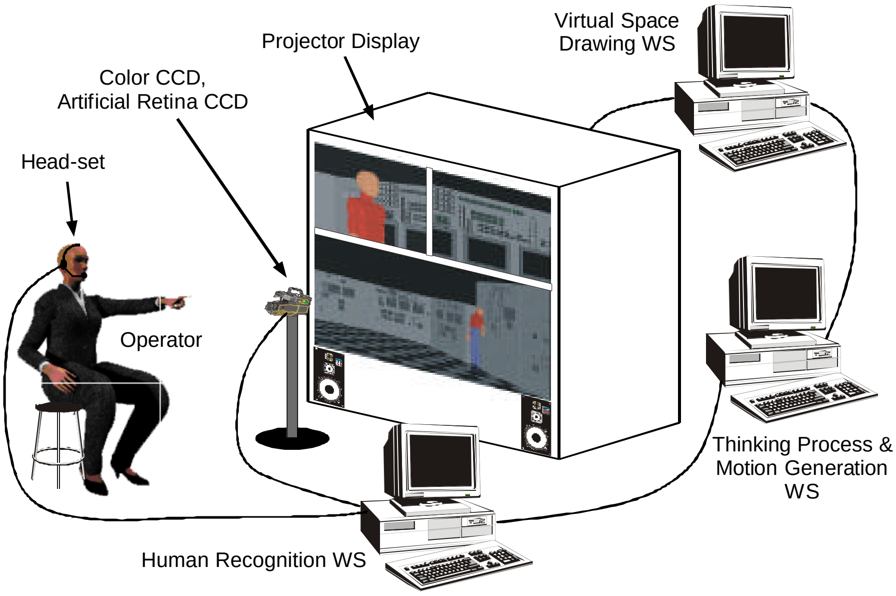

Figure 6 Future image of virtual collaborator based affective interface system

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