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Development of a Full-Scope Human Machine Simulator for Human Factors Experiments

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ABSTRACT

This paper presents the development of an Integrated Test Facility (ITF) that consists of a full-scope Human Machine Simulator (HMS) and some experimental measurement systems. This facility is aimed to experiment with the design of the control room environment and the human interaction as it relates to the control of advanced nuclear power plants.

I. INTRODUCTION

To establish human factors experiment facility named Integrated Test Facility (ITF), we have developed a full-scope Human Machine Simulator (HMS). ITF, which consists of HMS and experimental measurement systems, is an integrated human factors experimental environment for the evaluation of operator performance. This facility is especially aimed to experiment with the design of advanced control room environment and the human interaction.

The common features of advanced control room designs include compact workstations using visual display units (VDUs), large overview displays, computerized alarm systems, reduced number of operators, intelligent operating support systems, more automation than conventional ones, and information multiplicity.

The requirements described in various documents for advanced man machine interface system (MMIS) designs were analyzed to derive experimental evaluation items. Considering these items together with the common features, design factors were derived for the experimental evaluation of large overview displays and operator workstations.

We surveyed the cases of experimental evaluation in nuclear fields and general human factors experiments to classify the measurement methods used. Then, experimental data that can be collected by using the methods were categorized into system data, performance data, physiological data, and subjective data. The type of data and measurement devices that are effective for the evaluation of design factors were identified and related to each design factor. Also, three types of experimental facilities, which are a full scope training simulator, a desk top system, and an integrated human factors test facility, were evaluated with their advantages, disadvantages, and suitability for the experiments on the selected evaluation items.

Based on these analyses, we defined basic components of ITF and their requirements to include a full-scope simulator with experiment control and data acquisition functions, VDU-based operator workstations with a large display, and operator performance measuring systems [1-3]. The details of ITF have been designed from 1995, and the test of ITF was completed in March of 1997.

The basis for the simulator configuration, characteristics of systems and thermal hydraulic models for the HMS is the Korean Standard Nuclear Power Plant.

II. DEVELOPMENT OF A HUMAN MACHINE SIMULATOR

II.1 HMS Architecture Overview

HMS includes a full-scope PWR type nuclear power plant simulator with many VDU-based workstations. ITF has three rooms; main test room (MTR), supporting test room (STR), and experiment/computer room (ECR). Figure 1 shows the overall configuration of ITF.

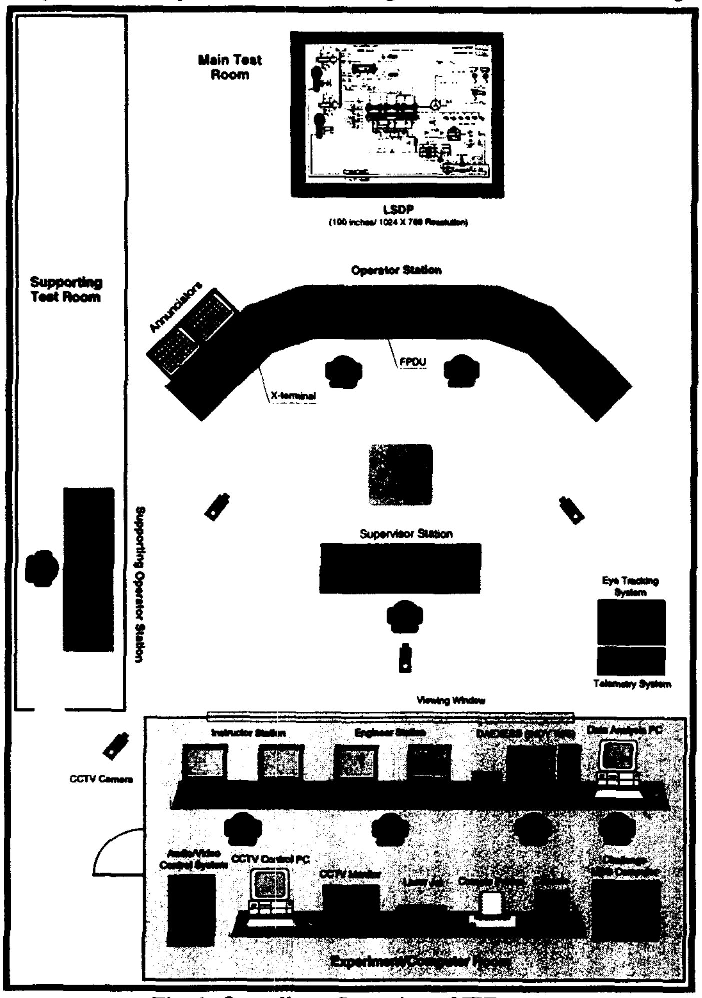


Fig. 1 Overall configuration of ITF

In the MTR, there are an operator station with many visual display terminals and alarm panels, a shift supervisor station, a large scale display panel (LSDP), and experimental measurement equipment. Reactor and turbine operators at the operator workstation obtain necessary information from hierarchical plant schematics, alarm windows, and trend graphs provided by HMI of the terminals.

Operators can use touch screens, keyboards, mice and trackballs in order to navigate among various display pages *and to control plant* components. The LSDP is located in front of the operator station to give information on overall plant status to the operators. The supervisor station has the same features as the operator station without component control functions. Figure 2 shows the picture of the MTR.

For experimental measurements, a telemetry system for physiological signal measurements, an eye tracking system, and a three dimensional motion analysis system for measuring operators' hand movements are located in the MTR.

The STR, which is smaller than the MTR, has an operator station in the same form as the shift supervisor *station in the MTR. With the operator station in the STR, subjects training and pilot* experiments can be performed independently to and simultaneously with the experiments being carried out in the MTR. Even more, operations with a new plant model or a new HMI design developed at the engineer station in the ECR are possible.

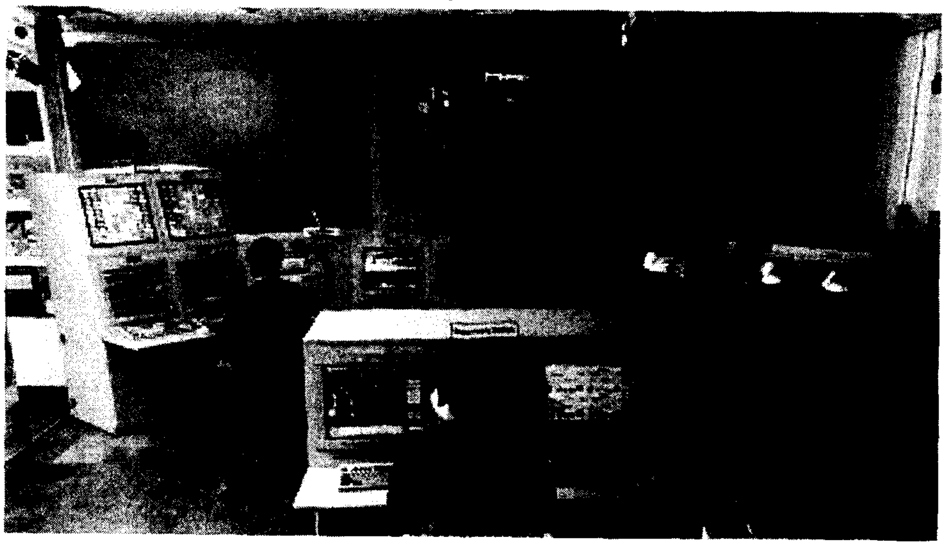


Fig. 2 The main test roon of HMS

In the ECR, there are a host computer with the plant simulation model and other necessary software and peripherals, an instructor station, an engineer station, a DAXESS (Data Analysis and Experiment Evaluation Support System) workstation, and an audio/video control system. The DAEXESS workstation is a system for experimental data analysis. An experimenter at the instructor station can test experiment scenarios for the preparation of experiments, setup the on-line data acquisition function, monitor and manage the experiments being performed in the MTR, cooperate with the operators in the MTR by doing local equipment operations, and analyze the history of operation done during the experiments. The engineer station in the ECR has functions to maintain HMS, and to develop and test a new HMI under the same plant model or a new plant model to be implemented later in the MTR.

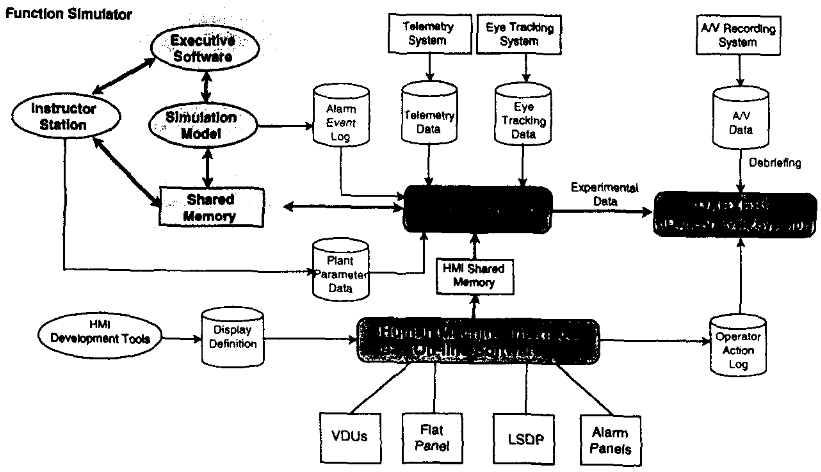


Fig. 3 Overall structure of ITF

As shown in Fig. 3, the software components of ITF include function simulator, human machine nterface software, SCADA (Supervisory Control And Data Acquisition) software for data collection and DAEXESS software. The function simulator consists of simulation models, executive software to run the simulation models, engineering tools to maintain the simulation software, and instructor software. The general data flows is that the instructor station controls the simulator executive which in turn schedules the simulation models. The models communicate through shared memory on the simulation computer.

The SCADA system monitors variables needed for the HMI graphic interfaces and also collects experimental data in historical data logs. The SCADA synchronizes the time of data from the telemetry system, the eye tracking system, and the three-dimensional motion analysis system to the time of host computer, and processes the data formats to be suitable for the DAEXESS. The historical data is available during the experiment to display trend graphs on the HMI devices.

The interface between the HMI software and the SCADA system allows control of the simulation models from the graphic interfaces. The instructor station software also collects specific experimental data for DAEXESS. After the experiment, some or all of the data files may be archived for subsequent analysis using DAEXESS.

The simulation computer complex uses two Ethernet Local Area Networks (LANs) to link together the various components of the HMS computer complex. Two networks are used to ensure adequate communication bandwidth. One LAN will be used for the display units in the MTR. The second LAN will be used for the display units, workstations, and other peripheral devices in the STR's and ECR's.

II.2 Instructor Station

The instructor station is used for the control of the simulated operation and for the supervising of the training. A graphic user interface of the instructor station provides pop-up menus for experimenters to select initial conditions, malfunctions, and plant parameters to be monitored, set simulation speed, change plant parameters directly, catch snapshot of current status, backtrack, freeze, restart, replay, and reset the simulation. HMS can simulate over 500 different malfunctions inclunding component level failures such as pumps, valves, electrical busses, breaker, etc.

II.3 HMI Navigation

In HMS, the navigation modes consists of four level hierarchical organization as follows:

- Overview Diagram (overall information of plant status),
- Level 1 Diagram (NSSS, BOP, Reactivity Control Overview, Alarm System Overview),
- Level 2 Diagram (24 pages subsystem),
- Level 3 Diagram (about 200 pages using SimDiagrams).

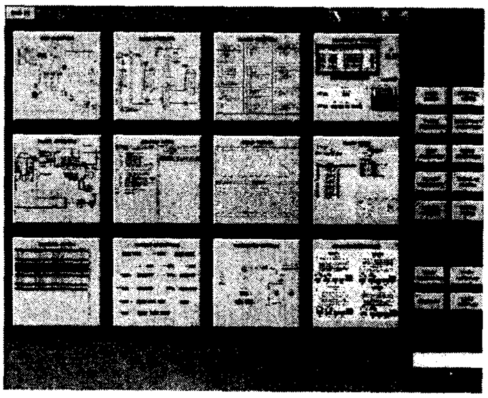
The control functions were added to the Level 3 SimDiagrams to allow the operator to control the simulated models. When a component (e.g. valve, switch, pump) on the SimDiagram is selected, the control panel area of the screen is used to display information about the component (such as value) and provide appropriate control functions (i.e., open/close) if applicable.

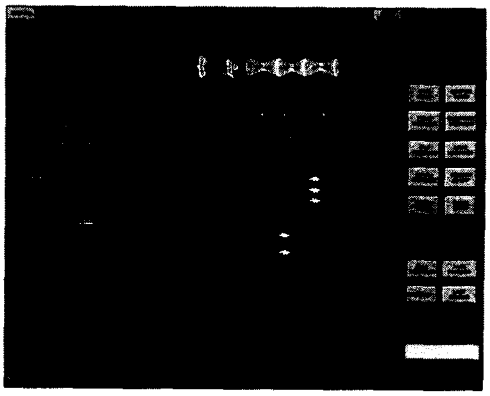
Navigation controls include direct navigation using command inputs, following flow paths on the SimDiagrams, or paging through the SimDiagrams for a given system using the Page Forward and Page Backward control buttons. The flow paths on a SimDiagram are off-page connector icons that point to another related SimDiagram where a flow path continues. Figure 4 shows some displays of the HMS navigation.

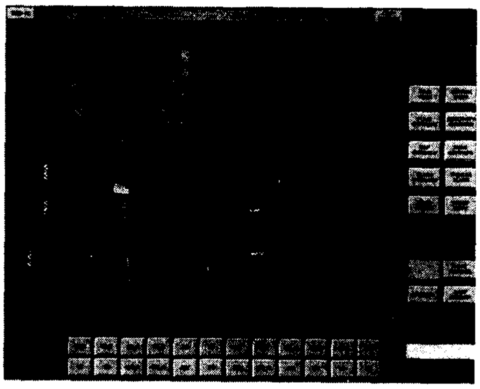
II.4 The SCADA System

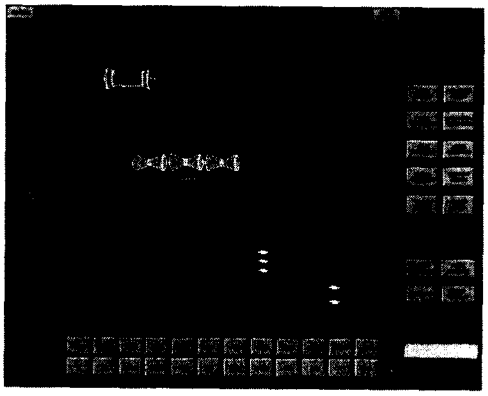
The SCADA system runs on the host computer and collects data from the simulation models and the executive system, and actions taken from the operator interface. The data collected is time-stamped with the simulator clock and saved. The data collected by the SCADA system is recorded for use by the HMI software. Some of the data can later be transferred to the DAEXESS system over the network.

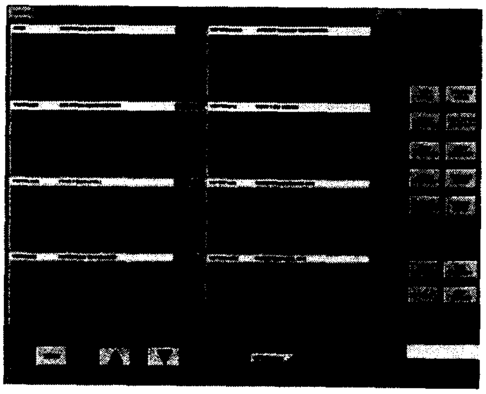
The SCADA system collects the following data:


(a) Main menu


(b) Plant overview


(c) NSSS overview


(d) BOP overview


(e) Trend viewer

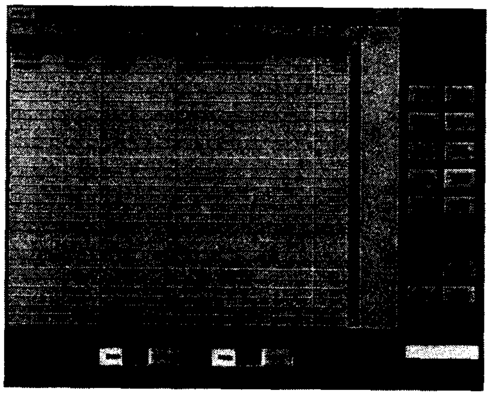

(f) Tabular alarm display

Fig. 4 Some displays of HMS navigation modes

- Historical Data: This data is collected from the simulation models and used by the HMI software trending function.
- Alarm Events: The SCADA system logs alarm transitions (OFF to ON and vise versa).

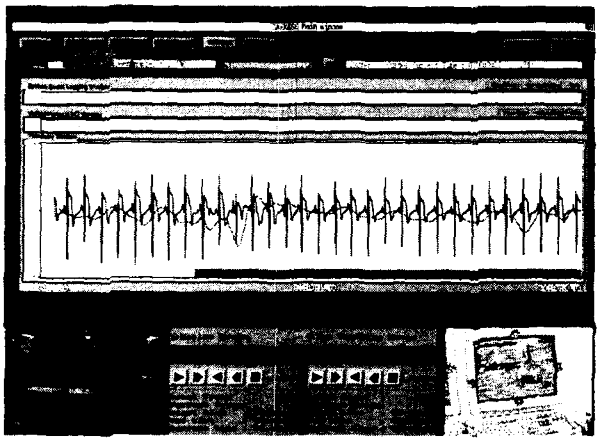


Fig. 5 The main screen of the DAEXESS system

Fig. 6 A test operator with an electromyogram (EMG) system

II.5 DAEXESS

The DAEXESS workstation is a system for experimental data analysis. Operators interact with the simulator through the HMI interfaces. Sequences of event log and the chronological history of plant parameters are produced respectively by the HMI software, simulation model, and instructor software of the host computer. The SCADA software in the host computer collects and stores the data.

The DAEXESS receives all the data from SCADA and integrates with audio/video records from the audio/video control system. With the data shown on the DAEXESS station, experimenters can perform various analyses, such as debriefing analysis, statistical analysis, operator performance analysis, and so on.

Figure 5 shows a sample display of the DAEXESS system. In this display, from the top, there are a menu bar, a time frame display bar, bars with marks for system event data and verbal protocol data, a telemetry data window, and two video display and control windows that are selective among the audio and video control system, the eye tracking system, and the three-dimensional motion analysis system.

Figure 6 shows a test operator with an electromyogram (EMG) system. Figure 7 shows a test operator with an eye tracking system. Also, Fig. 8 shows an audio/video control system.

II.6 Alarm Subsystem

The alarm subsystem consists of one Alarm Overview Display, multiple Alarm Detail Displays, and one Tabular Alarm Display. The Alarm Overview Display has one rectangular area (tile) per plant annunciator box. Each such rectangular area shows some information on the associated annunciator windows in this box. Each area blinks if any of the associated annunciators under it has not been acknowledged/reset. In tabular alarm display, new alarm messages are added to the bottom of the dynamic list. The user can scroll through the list. In addition to software alarm subsystem, there are also two convential alarm windows including 208 alarm tiles.

III. ACCEPTANCE TESTS

The purpose of acceptance tests is to evaluate the performance of HMS. The tests performed were divided into the following groups:

- tests of both instructor station functions and operator station functions,
- malfunction tests,
- transient tests,
- steady-state tests,
- start-up and shut-down tests.

Fig. 7 A test operator with an eye tracking system

Fig. 8 An audio/video control system

We have performed two acceptance tests, i.e., factory acceptance tests (FATs) and site acceptance tests (SATs). The target operating procedures used at the scenario tests are:

- emergency operating procedures (EOPs): 7 scenarios,
- abnormal operating procedures (AOPs): 36 scenarios,
- general operation: start-up/power operation/shutdown
- system operation: for about 50 systems and components

The results of the SATs showed that the test operators followed operating procedures well, navigating through various systems using mice, touch screen and command inputs at the VDU-based panels.

IV. CONCLUSIONS

This paper has described the development of ITF including HMS for human factors experiments. ITF has flexibility and expandibility to facilitate the experimental design and control, the installation and functional integration of advanced HMI and conventional control panels. HMS is designed and implemented to be suitable for experimental control, acquisition and analysis of operator performance data. In HMS, the HMI design is flexible and will allow experimentation with more advanced design alternatives.

In future, possible applications using HMS include:

- Experimental evaluation of advanced HMIs and rapid prototyping of user interfaces,
- Development of advanced HMS design principles and concepts,
- Experiments for the collection of human error data,
- Collection of operator performance data,
- Development and evaluation of operator support systems in connection with HMS.

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