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Virtual simulation of a nuclear power plant's control room as a tool for ergonomic evaluation

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ABSTRACT

This research deals with the virtual modeling and ergonomic evaluation of a PWR NPP control room, aiming specially with the assessing of the elapsed times spent by operators to control such safe-critical system. Secure Nuclear power plant (NPP) operation involves using guidelines that specify procedures to be followed by personnel. Control rooms' environments, though, present complex features and a series of mechanisms unpredicted by the guidelines, which must be faced accordingly. All these must be considered in ergonomics evaluations of NPP control rooms. This work proposes the use of virtual simulation through reusing a game engine platform, in which the real environment may be virtually modeled and people are able to virtually navigate and interact among themselves, to support ergonomics evaluation in adequating control rooms for licensing of NPPs. Virtual experiments results were very similar to previous ones collected in the real control NPP room, indicating that the former may be executed before the later as a means of prototyping design and evaluation, before executing any real intervention.

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1. Introduction

This work proposes the use of virtual simulations to aid ergonomics evaluations of operational tasks executed in NPPs' control rooms. As those simulations agree, in a good degree of accuracy, with the corresponding evaluations in the real environments, ergonomics evaluations may be performed first in those virtual environments (VEs), before carried out in the real ones. In the following, the importance of ergonomics evaluation of NPP control rooms and desks is emphasized.

The operation of NPPs, or industrial plants in general, take place in control rooms, where personnel should run the operation of such plants safely, to keep plants in normal conditions, or to bring them back to normal ones during the occurrence of any abnormal situations. For nuclear plants, these considerations are very strict, considering the potential hazardous effects of any abnormal conditions not faced adequately.

The existing interfaces in control rooms enable operators to track variables' status online through indicators located at different control desks in the whole control room. There are alarms indicators too, which indicate the occurrence of any abnormal conditions in one or more subsystem's modules. Also, operators should be able to change the plant's operational conditions anytime through actuator controls. Therefore, all these interfaces – indicators or controls – must be adequately located in the control desks and room, in such a way personnel are able to operate the plant safely in normal conditions, easily identifying all the variables' and alarms' indications and executing control actions. The adequate interfaces location is very important mainly for identifying promptly any abnormality and act appropriately in the occurrence of such unwanted conditions. In severe situations, the plant should be shut down (trip) readily. Control rooms must enable all this conditions for operators (ISO 11064, 2000).

After the accident at Three Mile Island (TMI), a critical review of nuclear power plant design in several countries, with respect to control room design, was determined by the International Atomic Energy Agency (IAEA). An additional chapter, addressing the Human Factors Engineering Program was included in the Final Safety Analysis Report (FSAR). This chapter was based on the standard review

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plan NUREG 800 (2001), which defined the nine areas for human factors review (NUREG 711, 2002). The requirements for a human factors engineering program will depend upon the human factors team qualification and experience, and on the number of human factors inputs. The following elements are recommended to be included in this program: operating experience review, functional requirement analysis, functions allocation, task analysis, staffing qualification, human reliability analysis, human system interface design, procedure development, training, human factors verification and validation (NUREG 711, 2002). The contributions of human factors engineering program are to ensure that the operator tasks are clearly specified, the number of staff, their functions and qualifications are adequate, the human system interfaces, procedures and training meet task performance requirements and are consistent with human cognitive functions. Guidelines for digital control room of nuclear power plants have been developed recently by the US Nuclear Regulatory Commission (NUREG 700, 2002). This guideline was developed to provide review guidance in nuclear power plant control rooms, and has one section dedicated to the HSI elements, one dedicated to specific systems and another one dedicated to workstation and workplace design.

Ergonomics and human factors research field find direct application in the design or upgrade of nuclear or industrial control rooms, aiming to improve operational safety and reliability. This research field deals with the evaluation of human behavior during operation experiments, by analyzing whether operators are able to track adequately variables' indications, to detect and identify correctly abnormal operational conditions from the alarms indications, and to act promptly to recover normal conditions. Based on these evaluations, indicators and controls may be more adequately placed in the control desks and in the control room, as well as the control desks themselves may be better located, considering the movement of operators within the control room during normal and abnormal conditions. Anything in the control desks or room designs could be changed to improve the overall operating conditions, based on ergonomics evaluations.

Virtual reality (VR) technology finds direct application for such tasks, since VEs may be designed to reproduce the real ones with high visual fidelity. Thus, evaluations may be carried out first in those VEs, before the tests in the real ones, if these occur. The later assumption – that the real environments may not exist – might happen in the design of totally new control rooms. Also, VE simulation approach may be used for the upgrade of existing ones. In this case, many modifications may be performed virtually, until achieving the desired performance. Then, the real environment may be modified accordingly.

This paper describes the use of a virtual simulation platform, based on a computer game engine that is freely available for educational and research purposes. Previous work has been done in reusing this platform for similar applications, as described in the next section. The current paper describes its reuse to reproduce an existing pressurized water reactor (PWR) NPP control room, to perform a comparative analysis between a previous ergonomic evaluation done in that real environment, to evaluation done using the corresponding VE. This paper thus emphasizes the VR technology use for the nuclear engineering field application.

2. Related work

2.1. Ergonomics evaluation of NPPs

As already mentioned, ergonomics evaluation plays an important role for industrial plants in general, and specially for nuclear plants. The reader can have an overview of this type of research in some references in this field, as (Malone, 1980; Hollnagel, 1985; Rollenhagen et al., 1989; Pikaar, 1990; Foley et al., 1998; Feher, 1999). Also, some guidelines deal with this matter, especially for nuclear plants (IEC 964, 1989; IAEA-TECDOC 565, 1990; ANSI/ANS-3.5, 1993; IEC 1227, 1993; IEC 1771, 1995; IEC 1772, 1995; IAEA-TECDOC 812, 1995; ISO 11064, 2000).

Previous research and development (R&D) has been carried out in *Instituto de Engenharia Nuclear – IEN* (Nuclear Engineering Institute), a research institute of *Comissão Nacional de Energia Nuclear – CNEN* (Brazilian Commission of Nuclear Energy), dealing with ergonomics evaluation of NPP control rooms and desks. More specifically, one R&D dealt with ergonomics evaluation of a PWR NPP. This research was developed during a D.Sc. thesis (Santos, 2003), when a case study was evaluated, considering personnel movement and tasks executed during an operation. Further results were published also elsewhere (Santos et al., 2008).

That R&D made use of video recordings collected during operation, and analyzed whether control desks and interfaces were adequately located or not. To be more specific, it was verified if personnel could move freely while executing their tasks, or if somebody could be blocked to move by other personnel; or if somebody could have his or her sight obstructed by other ones. Also, the times spent for the execution of each task were measured and registered. All this was carried out considering some predefined procedures.

Santos (2003) suggested the use of more advanced technology to aid in this type of evaluation. The current paper deals exactly with this, by making use of VR technology to verify in what degree it could aid in ergonomics evaluation of NPP control rooms.

2.2. VR simulation for the nuclear and related engineering fields

Computer-based technology has been used for many different applications, aiming to simulate real environments in computers, as a support for training workers in their tasks, for example. Especially, VR technology has been used for similar applications, through different approaches.

VR technology has been applied to the nuclear engineering field through different approaches. Concentrating in applications similar to the one reported in the current paper, one could cite other research groups have been using VR technology for simulating NPP control desks and control rooms, which results have reported in Drøivoldsmo et al. (2000), Drøivoldsmo and Louka (2002), Nystad and Sebok (2004), Sebok et al. (2004), Nystad and Strand (2006), Louka et al. (2006), Hanes and Naser (2006) and Markidis and Rizwan-uddin (2006), as typical examples. These works show how VR may be used to simulate and support evaluations in such important field as the design of nuclear and industrial control desks and rooms.

IEN's staff has also been using VR technology for the nuclear engineering field, mainly in two R&D lines: (i) simulating a PWR NPP control desk, and (ii) simulating a research nuclear plant for evaluation of dose received by personnel. The reader can find results related to the former application, the virtual control desk development, in the book chapter (Aghina et al., 2011). The paper (Aghina et al., 2012) gives deeper details in this development. The reader can also find results of the second application cited in a most recent related paper (Mól et al., 2010), or in a book chapter (Jorge et al., 2010) that summarizes them.

3. PWR NPP control room simulation

This section describes the case study developed in the current work. Subsection 3.1 describes the real PWR NPP control room in which this work was based, describing the first experiment executed. Subsection 3.2 describes the approach used for virtual simulation of the PWR NPP control room.

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