Use Cases and Design of a Virtual Cross-Domain Control Room Simulator

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ABSTRACT

Control rooms are facilities of central importance in many safety-critical domains (e.g., rescue services, traffic management, power supply). At the same time, they are characterized by a complex IT infrastructure that can only be integrated and adapted to a limited extent for research activities in the area of human-computer interaction. Previous work has already shown that virtual reality simulators of control rooms can be a suitable tool for these purposes. However, the solutions to date are very domain-specific, which makes it difficult to transfer knowledge and also to test aspects that are not primarily domain-specific (e.g., multimodal forms of interaction). This paper presents the concept of a domain-independent control room simulator and the development status regarding two use cases (build mode, simulation mode). Finally, further development and use of this approach are discussed.

KEYWORDS

Virtual Reality, Control Room, Safety-Critical Systems, Simulator

1 INTRODUCTION

Control rooms as "places for staff to undertake supervision and control of complex systems [...] often removed from the actual environment" [26] are central facilities in safety-critical domains. Whether it's coordination of emergency services, monitoring of industrial complexes or traffic management in cities, all this would not be possible today to the extent and with the demands made on security (of supply) without control rooms and professional operators.

However, demands and challenges in various control room domains are increasing due to social and economic reasons (e.g., smart grids in the energy domain [5], frequency of disasters due to climate change [16], more intelligent traffic control [15]), or additional sources relevant for situation awareness (social media, warning apps) [13].

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For this reason, researchers examine, among other things, the extent to which adaptations to the IT infrastructure, especially those aspects relevant to human-computer interaction (automation, input devices, output devices; collaboration options), can help operators continue to fulfill their responsibilities [1, 22, 28].

Testing concepts and prototypes under realistic or near-realistic conditions represents a major challenge. Interventions in actual control room operations are only possible to a very limited extent, and full-scale simulators are only available at a few locations and often booked for education and training.

For this reason, control rooms in virtual reality (VR) have been studied before (see section 2). While previous work has been devoted to domain-specific solutions, e.g., for nuclear power plants or rescue services, our work is devoted to a virtual cross-domain control room simulator. The idea is based on human-centered research activities described in section 3. Concept and realization are presented in section 4 and discussed in section 5.

2 BACKGROUND AND RELATED WORK

Considering control rooms in the context of VR applications has already been proposed and studied in terms of several aspects, including operation training [29], human-centered design activities (e.g., redesign of control room layout and systems) [4, 10, 19] or verification of workplace guidelines [6].

Typical usage scenarios are on the one hand the "concept design for [...] new control room[s]" [7] and on the other hand simulations of workflows. The latter are mostly realized with the help of game engine platforms "in which the real environment may be virtually modeled and people are able to virtually navigate and interact among themselves" [10]. Real environment refers to domain-specific artefacts and workflows (e.g., management of ambulances in a rescue services control room or monitoring of power grids in a utility control room). Cross-domain VR approaches that deliberately abstract from concrete artifacts and scenarios are not known up to the knowledge of the authors. In a consideration that goes beyond VR, reference can be made to work on individual aspects, such as forms of interaction in control rooms [27].

3 METHODS

Within the project PervaSafe Computing [9] devoted to scalable interaction concepts in control rooms as pervasive computing environments a human-centered design process is followed. It includes contextual inquiries at control rooms of different domains, more precisely energy control rooms, rescue service control rooms and ship bridges. The idea behind this is to identify domain-independent or cross-domain issues and approaches to interaction design for future control room workstations. The choice of application fields also reflects the distinction between stationary and mobile control rooms outlined in the taxonomy by [21]. In addition, 155 control room employees were questioned in an online survey about their workplace and their requirements for future assistance systems, and 9 control room experts were interviewed.

During these measures, it repeatedly became clear what had also been pointed out in previous work. Changes or studies in actual control room operations are only possible to a very limited extent, e.g., if operators were to wear data glasses on a trial basis without affecting the IT infrastructure in place. As a possible approach to meet this challenge, inspired by previous work, the concept of a virtual reality control room simulator was developed. In contrast to the previous work, however, the aspect of (possible) knowledge transfer should be given even greater emphasis - in line with the fundamental orientation of the research project mentioned in the beginning.

4 RESULTS

Subsequently, the basic concept and the 2 operation modes of the virtual cross-domain control room simulator are described. Software fundamentals and frameworks used will also be introduced.

4.1 Concept

Based on the previous work as well as the own research activities described before, the following vision was formulated: A multi-user domain-independent VR simulator of a control room should be developed, which integrates a construction mode and a simulation mode. It should be based on off-the-shelf hardware and software components. The latter point was taken into account by choosing the following components:

(1) HTC Vive Cosmos Elite system: It consists, among other things, of a headset for room scale VR, controllers with different pads and buttons as well as an adapter allowing the headset to be used wirelessly.
(2) Unity: A game engine that can be used for various 2D and 3D applications with support for VR [18, 25].
(3) SteamVR Unity Plugin: It represents "a collection of assets [...] to make creating VR experiences using Unity on OpenVR devices as simple as possible". [31].
(4) Mirror Networking: It is a framework for creating multiplayer games in Unity [8].

To achieve domain independence, simulation content had to be found that reflects specific aspects of control room work in abstract form. These include "task prioritizing" [17], "individual and group decision making" [23] and "problem solving" [24]. With regard to these aspects, established test procedures and tasks were researched that could be integrated into the VR environment (cf. [11, 14]). Examples are the d2 test of attention [2] and the n-back for mental workload [12].

The d2 test consists of the letters d and p, which are arranged in rows of characters marked with different numbers of dashes (see

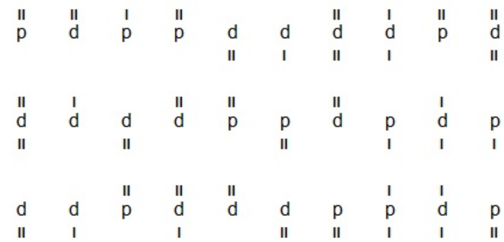

Figure 1: d2 test example By AndréWilke - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=17193961

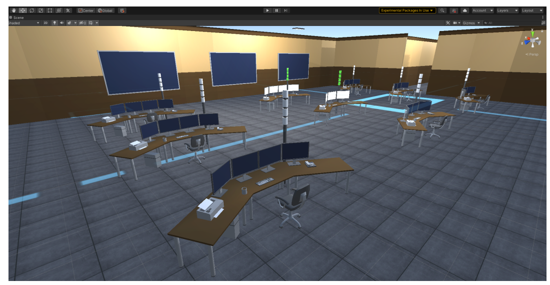

Figure 2: Classroom-like grouping of workstations as shown in [32]

Figure 1). Participants should cross out as many of the d marked with 2 dashes as possible in each row within a given time frame.

The n-back test (or n-back task) consists of continuously presenting the participant with stimuli in visual or auditory form and asking the participant to confirm if one of the stimuli has already been shown/played exactly n steps before. By varying the step size n, the difficulty of the task can be controlled, too.

Their integration into the VR control room will be discussed in more detail in section 4.3. Before this, however, the mode of the VR control center that is chronologically used first will be explained in the following section.

4.2 Build Mode

The Build or Control Room Layout mode allows users to set up a control room with typical artifacts (e.g., tables, chairs, IT components, alarm solutions) in a largely arbitrary manner (see Figures 2 and 3). Different workplace situations, both in terms of private workstations and shared artifacts (e.g., wall-sized screens), can be experienced in a vivid way. Individual elements (e.g. a screen) can be freely placed as well as more complex structures (e.g., an entire workstation or a wall installation).

The setup can be done either directly within the VR application (see Figure 4) or, which is recommended for more extensive setups, using a web application (see Figure 5). However, the latter currently still requires a conversion step using the Blender application (https://www.blender.org/) in order to convert the Graphics Language Transmission Format exported by the web applications into the FBX file format required by the 3D Engine.

Figure 3: Circle-like grouping of workstations following the approach by [30]

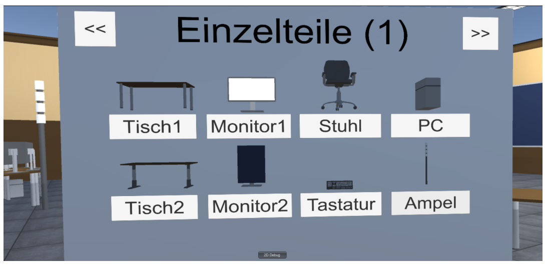

Figure 4: Selection menu for individual artifacts ("Einzelteile") of a control room setting

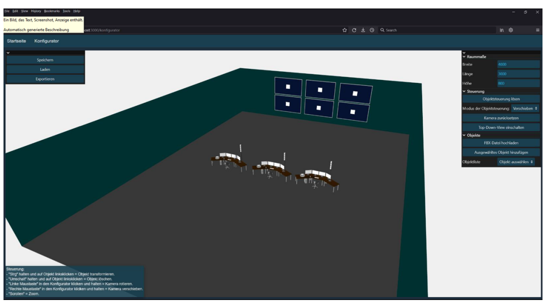

Figure 5: User interface of the web-based control room layout tool

Completed control rooms can be saved and made available to other users if necessary. This also allows existing models to be further developed by multiple people or over time.

4.3 Simulation Mode

The simulation mode enables the completion of predefined scenarios. If, for example, the user occupies the workstation, as shown in Figure 6, one or more of the previously mentioned tests begin. In the course of use, further challenges can be added. Depending on the test, feedback is given directly or after a certain period of time (see Figure 7).

5 DISCUSSION

As illustrated in the previous section, the initial version of a multi-user domain-independent VR control room based on off-the-shelf hardware and software components has been realized in a software-technical sense. In particular, a flexible construction mode as well

Figure 6: Exemplary setup of a workstation with different tests running in parallel

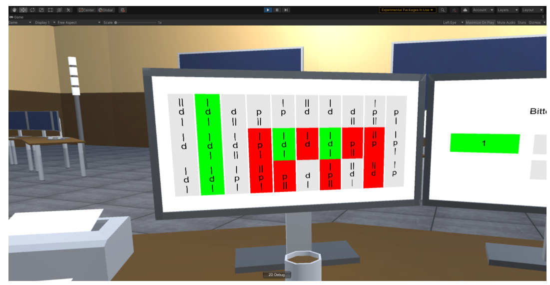

Figure 7: d2 test on attention and concentration [3] at one of the workstation screens

as a simulation mode configurable with different tests could be realized. This stage of development represents on the one hand a promising basis for studies with operators and at the same time clear limitations.

Development has shown that it seems possible in principle to abstract from domain-specific content and integrate validated test procedures into the VR control room environment. Future work will be devoted to conducting usability tests and other user-oriented evaluation steps. The primary questions to be answered are to what extent the cross-domain approach is understood and accepted by operators from specific domains. Subordinate to this, but not unimportant, is the question of the extent to which the construction mode offers a sufficient selection of artifacts to take account of any domain-specific peculiarities.

In addition, the current state of development represents control rooms in their present form. More innovative forms of input and output (e.g., voice and gesture control) have yet to be integrated, as do previously little-used work tools such as multi-touch tables. The same applies to the connection of sensor technology which might allow for conclusions to be drawn about operators’ cognitive and emotional states.

Furthermore, Social VR challenges [20] need to be addressed. How and in what form the operators of a VR control room can perceive each other, communicate and cooperate will be the subject of further research. But here, too, technical foundations have been laid.

6 CONCLUSION

Control rooms are central to the lives and well-being of people in many areas. They are also a challenging context for human-computer interaction research. Virtual reality simulators of control rooms can be a tool to realize and test concepts beyond the current state of the art. While previous work has studied domain-specific VR solutions, a cross-domain approach and its implementation was introduced in this work. Future research will have to show whether it will be understood and accepted by control room operators and ease transferability of knowledge between control room domains.

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