Cave automatic virtual environments for research into occupational safety and health – Practical recommendations and solutions for the construction

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ABSTRACT

Virtual reality (VR) is a methodology for the investigation and evaluation of human-machine system design from early stages in life cycle product development. This enables the integration of ergonomic design strategies and principles in product design. Moreover, it makes VR increasingly important for applications in occupational safety and health at work such as the development and evaluation of new safety concepts or the execution of usability studies in human-machine interface design. VR is also a technology for the simulation of dynamic environments and enables a user to interact with representations of real or imaginary worlds.

VR technology nowadays is already available as off-the-shelf solution, with the consequence of limitations for potential applications and with constraints of validity of VR results for systems design. Over the past year, the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) has built a VR system designed to meet their specific requirements for research into accident prevention and product safety. The paper will concentrate on technical issues of the design process according to potential applications and ergonomic design requirements as well as on solutions and practical recommendations that lead to the development of the VR system within the IFA.

1 INTRODUCTION

Virtual reality (VR) has grown into a simulation tool for industrial product development and into a methodology for applied research in human-machine system design and evaluation. Application of VR in different sectors of industry and services such as manufacturing, process industries, transportation or medical engineering suggest suitability for product and training design and evaluation. VR has also been matured to facilitate efficient investigations with the potential to substitute more traditional research at shop floor level while being careful with human, material and financial resources /1/. Improvements in VR technology with more appropriate adjustments for human information processing in human-machine interaction made VR also attractive for training and product design issues in occupational safety and health /2//3/. Substantial research efforts in accident prevention and product safety using VR have already been demonstrated advantages of VR applications in occupational safety and health /3//4/.

VR is also a technology for the simulation of dynamic environments and enables a user to interact with representations of real or imaginary worlds. Developments over the last decades resulted in a boost of representation quality as regards complexity of visualisation (e.g. process control plant) and dimensions in perceptual demands (e.g. visual, acoustic, or haptic feedback). The maturation of VR also found its way in the occupational safety and health domain and has widened the areas of application (e.g. training, services design, and machinery design). Once VR technology is set up properly, it allows for cost effective operation because technical system components under investigation often are already available in 3D digital formats.

VR technology nowadays is already available as off-the-shelf solution, with the consequence of limitations for potential applications and with constraints of validity of VR results for systems design. Over the past year, the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) has built a VR system designed to meet their specific requirements for research into accident prevention and product safety. This system is the main installation within the Virtual Reality Applications (ViRAPPS) laboratory of the IFA.

2 TECHNICAL ISSUES

Several criteria for VR system design have been established beforehand in order to meet the demands for the simulation of different applications of work processes. To allow for an undisturbed and realistic visualisation of work environments and large or interlinked machines, it has been seen necessary to go for rear projection on a curved presentation wall with 3 x 8 m projection area (see layout in Figure 1). The operator can move in a 7 m² space in front of the presentation wall (custom-built by VISCON GmbH, Germany).

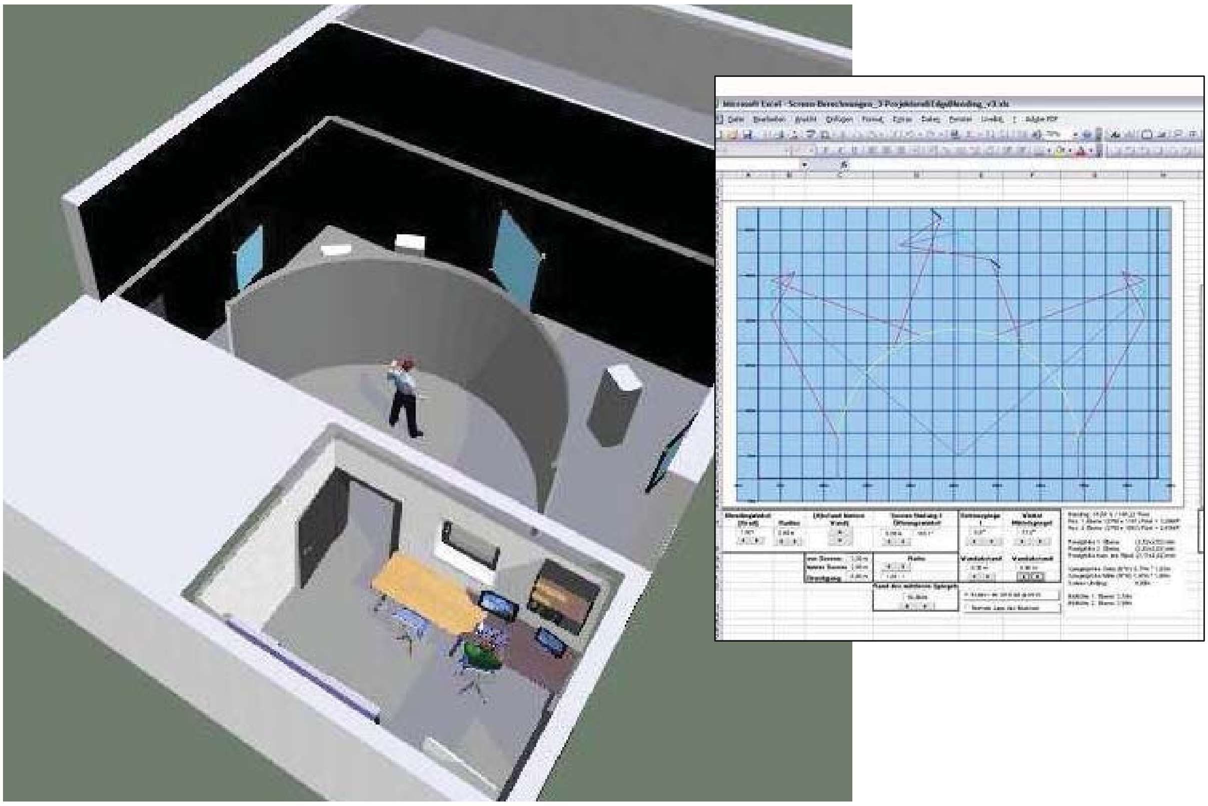

Figure 1. *Calculating the layout of the Virtual Reality Applications (ViRAPPS) laboratory of the IFA.*

Size and angle of the projection have been defined according to visibility and immersion requirements within the work space in front of the projection wall. The wall represents a 164° circle segment of 2.8 m arc radius. The physical dimensions allow the workspace and projection area big enough to fully cover the human field of vision for stereoscopic depth perception when facing the projection area (see Figure 2). Dimensioning also facilitated interaction of human operators with large stationary machinery.

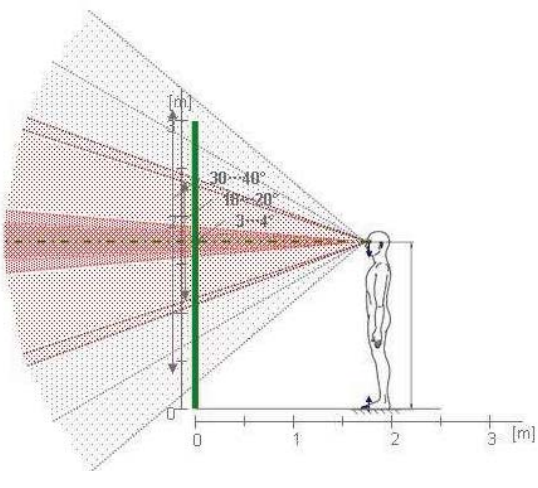

Figure 2. *Field of vision in front of the projection area.*

Figure 3 shows the networking topology and the main subsystems as built so far. Most devices operating in the VR system are interconnected via Gigabit Ethernet.

Tracker system: Four infrared cameras for motion capturing (VICON®, OMG plc, UK) mounted on top of the projection wall served the match between operator head movement and the dynamic adaptation for visualisation of the virtual world.

Projection system: The assessment of different stereo projection systems resulted in a system based on interference filter technology (Infitec®, Infitec GmbH, Germany) being most appropriate because of high colour qualities, high refresh rates for the projection and its compatibility with operator body movements. This interference filter technology was applied for 3D rear projection with three pairs of high luminance beamers and for operator glasses to experience depth cues in three-dimensional space.

Eye tracking system: The participant can be equipped with a mobile, head-mounted eye and gaze tracker (iView® X HED-MHT, SMI, Germany) and still experience full freedom of movement inside the work space. This system features fully automatic eye tracking – and not only relative to the head position: In combination with the head tracking, absolute gaze tracking in relation to the VR objects is made possible. Additional head mounted video recording of the scene is continuously forwarded into in packages for video analysis.

VR Software: After a long-lasting evaluation and decision process, the IFA decided to go for an integrated commercial VR software (Vizard®, WorldViz LLC, USA) which is designed for building and rendering virtual worlds. It provides rapid prototyping of interactive 3D contents. One of the critical success factors is that even someone with little programming experience can develop or at least adjust VR scenes and animations. This is provided by a simple scripting language called Python.

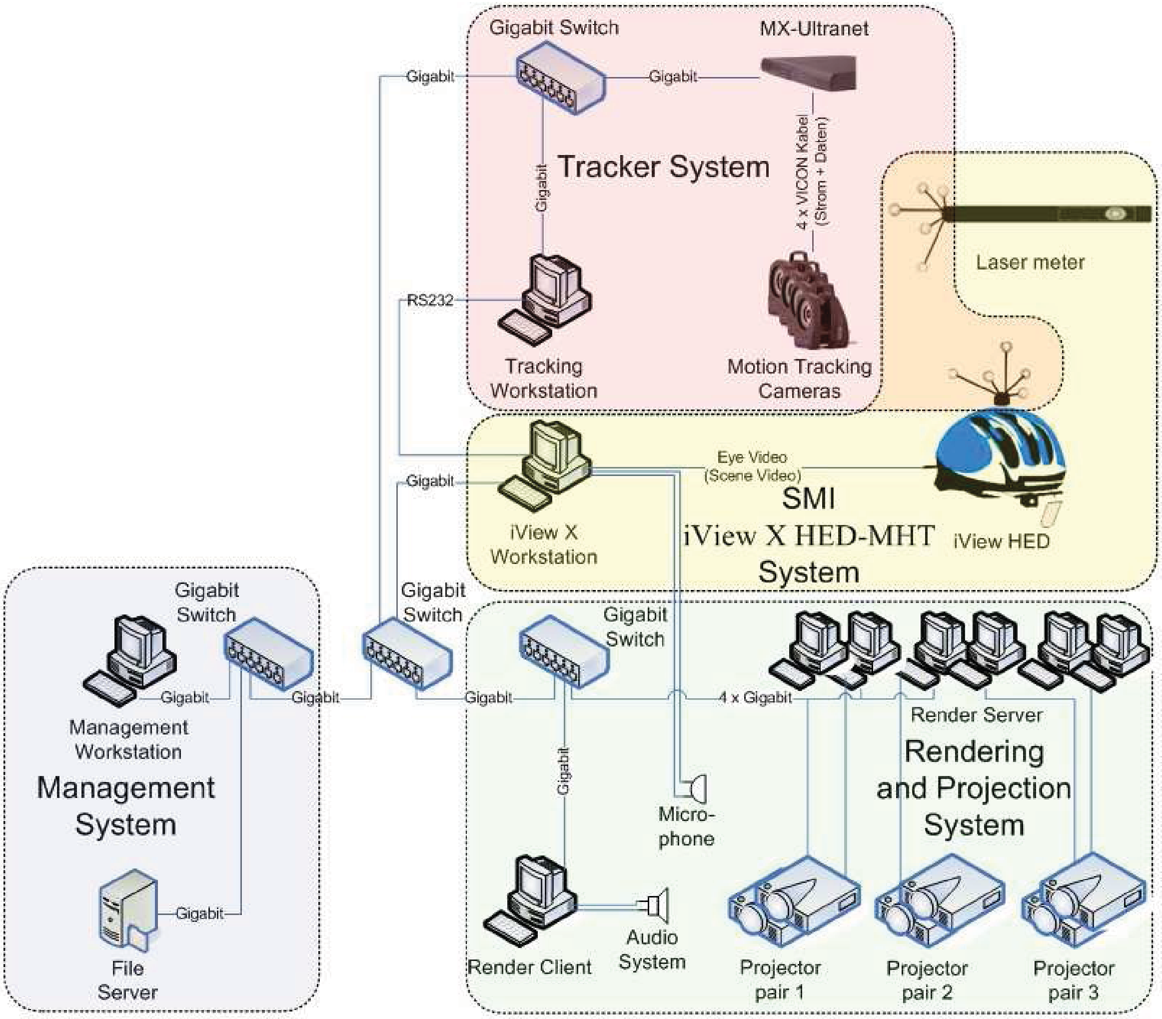

***Figure 3**. Topology of the VR system at the IFA.*

VR system development also required efforts to free laboratory space within the IFA, high and large enough to accommodate the VR projection including frontal activity area, the control room and the back stage for mirror rear projection. The projection on a curved screen provided additional design challenges in that three pairs of high luminance and high resolution beamers were used as stereo projection units. Special designs were required for stands and flexible adjustments of mirrors and beamers (manufactured by the IFA workshop). Besides edge-blending and colour calibration the curved screen design needed deformation of the projection by static warping; in addition, dynamic warping was necessary to allow for realistic representations in case of operator movement. These functions have been successfully implemented by VIOSO GmbH, Germany.

Tests during the development of the VR laboratory identified echo effects alongside the large and curved presentation wall. This effect could already be significantly reduced by installation of sound absorption on the ceiling above the operating space. The VR laboratory is built up without windows because exposure to direct sunlight or airborne dust would negatively affect projection qualities. Climatic Conditions in the VR laboratory were therefore given special emphasis by installation of an air condition.

3 CONCLUSION

At the moment the CAVE within the IFA provides high quality full functional dynamic visual representation. Audio representation is under development and among the next steps will be the implementation of procedures for data analysis of tracking for eye, head and body movements to allow for projection control and research into accident prevention and product safety. With the current state of development it has already been possible to run first experiments /5/.

In addition, a small scale VR demonstration of a workplace with collaborating robots has recently been presented at the International Trade Fair and Congress on Safety, Security and Health at Work (A+A 2009) and a project on the validity of VR representations for usability studies in real world human-machine system design is under way. Projects of the near future will deal with the development of new safety concepts and ergonomic requirements for the design of workplaces with collaborative industrial robots (see Figure 4) and will cover further human-machine system design issues in occupational safety and health.

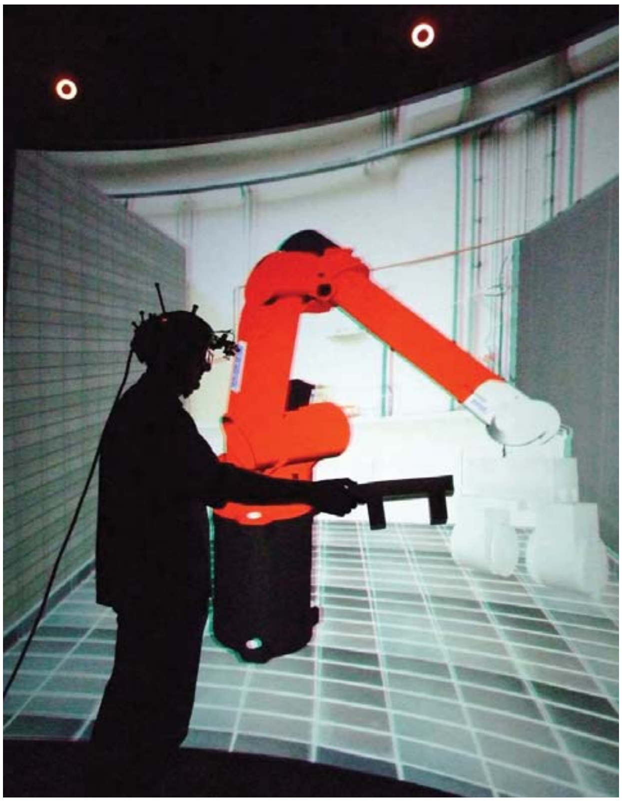

Figure 4. *Experiment with simulated collaborating robot.*

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