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Risk Analysis (Assessment) Using Virtual Reality Technology - Effects of Subjective Experience: An Experimental Study

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Abstract

Depending on the specific design phase and relevant goals, engineers have various options to visualize machine tool development. This study examined two types of visualization (e.g. concerning complexity, colors, animations, vividness) using VR technology. Over 25 experts were asked to identify and assess hazards in two 3D-models that differed in complexity. Besides technical aspects, we tested whether psychological aspects such as sense of “being there” and the quality of the risk assessment were affected by the type of the 3D-representation. Furthermore the relations between the user`s traits (e.g. conscientiousness, risk perception, etc.) and the properties of the 3D-models were explored.

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Keywords: VR-Visualization; Product development; Presence; Risk perception

1. Introduction-Virtual reality-based engineering methods

The enrichment of digital geometric models of machines with non-geometric technical information in an early phase of machine development is state of the art. All subsequent engineering processes during the product life cycle enrich the original CAD-model further. Digital mock-ups are virtual models for testing purposes. They can be used for different purposes such as geometric representations combined with certain functionalities verified by means of multi-physics simulations (functional mock-up). These forms of virtual testing are based on specific criteria and quantitative evaluations, a process which aims at avoiding malfunctions of the later product. Virtual reality (VR) models can be understood as a special kind of digital mock-up that strongly improves the imagination of users.

A VR-system is configured for a specific number of projection screens, which varies depending on the system. In general, the more projection screens are used the higher the immersion (i.e. sense of “being there”). The geometric models used in VR can provide impressions of visually perceivable properties (stereoscopy). An advantage is the true-to-scale VR-model, which is suitable for assessments where the size of a machine or object is important, e.g. ergonomics, safety issues or very large objects. Contrary to the above mentioned functional mock-up, virtual testing with a VR-model is often a qualitative evaluation based on observer evaluations.

The VR-model is part of a VR-scene (the virtual environment) which includes objects (3D-geometries, light sources, cameras etc.), and object-related properties (colors, textures) and their interrelations. Especially in engineering fields such as quality assurance, risk assessment (RA), production planning, and professional trainings, VR technology offers major advantages.

The iterative process of a RA prescribed by law [1] (Fig. 1) aims at risk reduction by means of design changes, complementary protective measures or - as a last resort - user information. The later a risk is detected the more expensive necessary improvements are. For that reason it is recommended to start the RA in a early phase of development. The so-called harmonized standards help the machine manufacturer to comply with the directive of machinery [1]. As the path to identify risks is not exactly prescribed, risk assessment always includes subjective aspects.

Directly after the publication of the directive of machinery [1] in the IMMMA project, VR-models of several

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types of machines have been used to support the legal procedure of the risk assessment [4] environment).

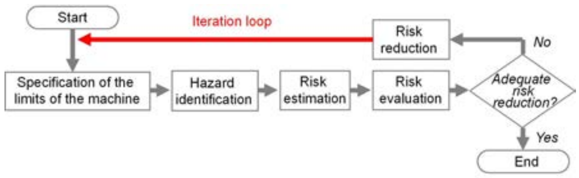

Fig. 1. Process steps of the risk assessment and risk reduction based on [2,3]

An example of civil engineering is described in [5], where visualization is especially helpful in large scale objects. The added value of the VR is that in objects such as river locks critical situations and risks can be observed in chronological order. One issue is emphasized: The components contained and the level of detail is to be discussed [6] for that purpose.

Another application, the Failure Mode and Effects Analysis (FMEA) [7], was established in the field of quality assurance. Here, VR offers the advantage of providing more vivid impressions of the object. A software platform for a VR-based FMEA is conceptually described in [8].

The quantitative evaluation of a machine is mainly based on objective measurement results. Contrary to that, the assessment of a machine concerning qualitative aspects like safety issues is based on subjective evaluations, which also means that biases can occur due to under- and overrating of certain criteria. Altough there will always be a difference between the virtual model and the real machine, this effect is often neglected. On the other hand, the virtual models can be enriched with specific visual effects or animations. The existing conflict of goals can be explained by the adaptation of the CAD-model for purposes such as "navigation in VR", which is associated with a drastic reduction of number of components and detailed features. Yet, according to which rule or guideline does a design engineer reduce the CAD-model? Are there safety relevant functions which have a relation to a certain suppressed or deleted component? Whereas a special highlighting of component could point out special geometry or parameters, the same highlighting can simultaneously take the engineer's attention off other important details. Another example is shown in [9], where a color-coded value visualization of component was implemented. Or, additional information such as the energy consummation of electric motors will be visualized differently [10]. Thus, the overarching question to be answered is how the components of a VR-scene influence the subjective experience of the engineer.

As Bricken [11] argued the laws of virtual reality are not based on physics, but on psychology. Seen from a different angle, the approaches of the two scientific fields form two essential parts which together constitute the special effect of virtual reality. In this vein, Slater and Wilbur [12] distinguished "immersion" and "presence":

- immersion: an objective description of aspects of the VR-system such as field of view and display resolution
- presence: a subjective phenomenon such as the sensation of being in a virtual environment.

When you enter a virtual reality scene you feel like you are right there. This experience is called presence. There are several theoretical accounts and definitions for the concept of presence [13]. For example, Heeter [14] defined three dimensions of this experience: personal presence (the extent to which the person feels like he or she is part of the virtual environment), social presence (the extent to which other beings - living or synthetic - also exist in the virtual environment) and environmental presence (the extent to which the environment itself interacts with the person). Another prominent definition was given by Schloerb [15] who distinguished two types of presence: subjective presence (the likelihood that the person judges himself or herself to be physically present in the virtual environment) and objective presence (the likelihood of successfully completing a task in a virtual environment).

Presence is influenced by technology-related and user-related factors [16]. User-related or internal factors refer to factors that vary between users (i.e. inter-individual differences) such as age [17], visual ability [18], cognitive abilitiy [19,20] and experience in using digital media or playing computer games [21]. Furthermore personality traits have an impact on presence. For example, immersive tendencies [22], locus of control [22,23] which is defined as ''the degree to which persons feel that they control events in their own lives or that such events are influenced by outside forces, chance or luck'' [24] are related to the intensity of the sense of being there. Finally, the results of Weibel et al. [25] and Parsons et al. [26] indicate that personality traits such as openness to experience, and extraversion are positively related to presence. Nevertheless, the results are not totally conclusive and some contradictory results suggest that the relationship between presence and individual factors is dependent on the task [27]. Further investigations are necessary concerning task-related knowledge as a user-related factor and its assessment in virtual environments.

Presence is a relevant concept as it does have an important impact on cognitive performance [28]. Various studies showed that an intense experience of presence enhances attention and cognitive resources for task-related performances [29,30]. Based on the fact that presence enhances learning performance, there have been efforts to use VR in supporting different forms of training and assessment. For expamle, Perlman, Sacks & Barak [31] transferred these findings into engineering and construction and showed that construction superintendents, who assessed hazards in a construction project using virtual reality, identified more hazards correctly than subjects who worked with photographs and documents.

2. Test method and hypotheses

Due to the manifold purposes that virtual models of a machine have in various fields of engineering, it does not seem feasible to develop one single guideline for creating VR-scenes for the purpose of analyzing subjective experiences and other non-technical (psychological) aspects. With this in mind, it is necessary to develop a general approach in systematically deriving VR-based test scenes for specific