Work Space Layout and Evaluation Using the Elbedome 2.0 Virtual Environment

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Abstract. The paper describes the need for industrial virtual reality (IVR) applications that validate innovative work spaces, which include human-robot collaboration and cognitive assistance systems, factoring in noise, lighting and ergonomics. The capabilities and limitations of two different IVR systems based on head mounted displays (HMD) and mixed reality (MR) are compared. A brief description of the Elbedome 2.0 MR environment is followed by the conclusion and outlook.

Keywords: virtual reality, mixed reality, work space layout, ergonomics

Introduction

In response to manufacturing's growing demands for responsiveness, quality and complexity, Industry 4.0 advocates comprehensive interconnectivity of manufacturing systems, real-time capable digitization of manufacturing processes and performance, and assistance from smart work systems [1, 2]. Designing such future work systems [3] includes such challenges as safe human-robot collaboration and physical and cognitive assistance systems for workers and maintenance technicians. Despite their growing complexity, such work systems nevertheless have to remain responsive to new demands, i.e. be modifiable or upgradable. Such systems, especially in assembly stations, should, however, primarily provide workers effective assistance when they are performing their individual jobs as well as exactly the physical or informational assistance that they need and accept. Not only physical exhaustion but primarily also cognitive and psychological stresses caused by complex, frequently changing and time-sensitive work processes have to be prevented, which can not only lead to drops in performance and quality but also accidents at and absences from work due to stress.

Virtual Reality Work System Design

Shortening planning cycles in Industry 4.0 necessitates evaluating ergonomics, usability and functionality parallel to planning, i.e. even before a work system is really available. Simulation methods, e.g. for ergonomic analysis, can be employed for component parts but involve complex modeling. This is where integral interactive models, so-called industrial virtual reality (IVR) [4], which visually, acoustically and functionally simulate work systems, assembly stations in this case, and enable empirical analyses, can help. Advanced head mounted displays (HMD) and appropriate interactive devices with limited haptic feedback combined with IVR are particularly suited for giving subjects a sense of being present in a work space and being able to perform the assembly process being tested. Movements of the limbs of subjects wearing an HMD have to be scanned by a motion tracking system in real time and assigned to their avatars, i.e. their representation in virtual reality, to enable subjects to sense them (see Fig. 1). Another benefit is that the captured motion data can be used along with standard worksheets (e.g. EAWS) to assess motion sequences.

Fig. 1. Subject with an Oculus Rift DK2 HMD and the target set for IR tracking (left), the subject's avatar in a virtual work space (center) and the subject's view through the HMD (right)

Industrial virtual reality can be used to safely test and evaluate assembly stations with collaborative robot systems (see Fig. 2), maintenance processes in robot cells (see Fig. 3), and other hazardous work processes. Psychological stresses caused by noise, poor lighting or hectic work environments, which are increasingly becoming the focus of attention, can also be simulated and incorporated in an assessment.

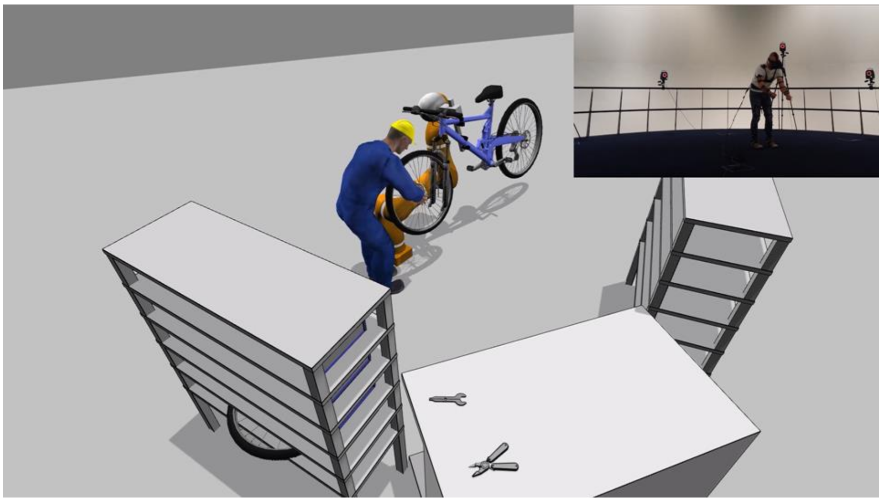

Fig. 2. Evaluating a work process at an HRC assembly station with a KUKA LBR iiwa for immobilization

Fig. 3. An interactive HRC work process

Virtual reality based on HMD is nevertheless not free of feedback, especially when stress parameters or process times are being measured and the effect of such interference has to be ascertained by using standardized questionnaires before and after the evaluation. Interviews are usually based on the Igroup Presence Questionnaire (IPQ), a scale for measuring the sense of presence experienced in a virtual environment (VE) [5], and the Simulator Sickness Questionnaire (SSQ), which determines the degree of cybersickness experienced by VE users of [6]. The additional costs and labor for the real-time-capable and sufficiently precise motion tracking systems essential for detailed representations of individuals' avatars are drawbacks. Current HMDs such as HTC's Vive or Facebook's Oculus Rift, on the other hand, only enable capturing transformations of heads and hands in a small range free of visual obstructions. Furthermore, the unspecific haptic and tactile feedback, conveyed by different vibrations through an HMD's hand controller, combined with the absence of weights of the loads is inadequate, especially in assembly processes. Given the more complex technical requirements, latencies of tracking and visualization, and restrictions on natural communication among subjects, work processes performed by several subjects simultaneously can only be reproduced to a limited extent with this method.

Combination with Real Work System Components

At present, standard worksheets as well as empirical-analytical methods based on motion capturing can be used to assess the ergonomics of real work systems. Subjects' ability to receive real haptic feedback and to sense the weights of the loads is an advantage. The late availability of the real work space and environment is a drawback. Simplified prototypes or sets of flexible work space modules can be employed to perform these tests under laboratory conditions parallel to planning (see Fig. 4).

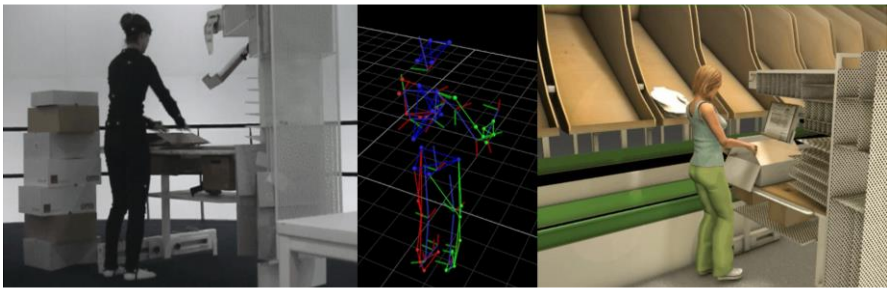

Fig. 4. Work process in a work space prototype (left), biomechanical model (center), and embedding in the planning data (right)

Current research projects are focusing on lessening the drawbacks of methods based on HMDs by linking real work system components with virtual IVR models in one so-called mixed reality. An assembly station is represented by a simplified replica based on a module set or a prototype and ambient conditions such as light, noise and surrounding manufacturing systems and processes simulated by IVR or 360° stereo films. This makes it possible to receive genuine haptic feedback and sense real weights of the loads. Virtual reality can no longer be represented in this case by means of HMD's, though. Instead, this has to be done by stereoscopic projection in the subject's environment. Since subjects are able to see and sense themselves, motion capture can be dispensed with if the kinemetry is analyzed some other way. Although the interference from feedback has to be studied, it is expected to be lower in this setup. A mixed reality system that allows such a setup technically and physically is currently under construction in the Elbedome 2.0 at the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg, Germany.

The Elbedome 2.0: An Industry 4.0 Laboratory

The Elbedome 2.0 is the next evolutionary stage and logical continuation of the virtual environment display system [7] opened in 2005 and is focused on the information technology challenges of Industry 4.0. The size and shape of its projection surface immediately set it apart from standard systems used in industry. Its size allows realistic representation of complex and large contents, the presence of many parallel users and the integration of real work systems for mixed applications consisting of real and virtual components. Its cylindrical-hemispherical projection surface measuring 16 meters in diameter allows a continuous omnidirectional stereoscopic representation of virtual contents in a 360° panorama including the floor. Elbedome 2.0 picks up where standard systems reach their limits, thus providing ideal conditions for industrial applications that involve large numbers of people, are highly complex and increasingly require communication.

Elbedome 2.0 was designed to be an Industry 4.0 laboratory and will be available in the future as an innovative tool for research on current issues including not only mixed reality methods for smart work system design and assessment but also monitoring and control of commissioning and operation of Industry 4.0-capable manufacturing systems using cyber-physical systems (CPS), reliable semantic, technical and organizational interoperability (Virtual Fort Knox [8], Industrial Data Space [9]), and sustainable qualification [10] and creativity enhancement in industrial planning.

This will make it possible to us the Elbedome 2.0 in the future as a bidirectional monitoring and control interface to cyber-physical systems created out of von digital models in product and process planning. The heterogeneous models synchronized with the real system have to be converted into a visualizable, interactive and functional industrial virtual reality model and coupled with real-time data from the manufacturing system. This enables representing complex available data manageably and graphically for people to be able to evaluate and verify the complete system’s current performance and function. Crucial knowledge is obtained especially whenever current data sets are not only used but also compared with simulated conditions, e.g. operative forecasts or troubleshooting, and, conversely, the real system can be altered. In the use case described here, the interface to the real manufacturing system’s CPS makes it possible not only to represent simulated, but also past and present situations in the environment.

The Elbedome 2.0 will provide a space of 50 m² in its center (see Fig. 5), which can be used purely virtually for floor projection as well as for MR scenarios and to design real or prototype work systems. What is more, all important media (power supply, network, compressed air, etc.) are also provided to connect tools, robots and machines inside it. The floor projection system in this area can be used to simulate different lighting situations.

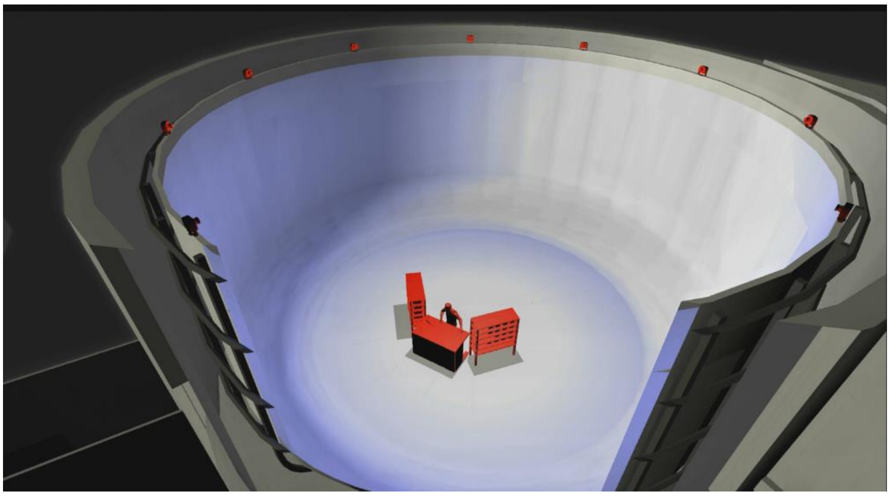

Fig. 5. Elbedome 2.0 with a real work system (sectional view)

Additional elements such as robots' dynamic danger and safety zones, assistance information on individual process steps or interactive menus can also be projected. A work space's environment can be represented omni-directional-stereoscopically on the surrounding projection surfaces, either using a IVR model or 360° films filmed in the real factory. The sound systems delivers realistic sound effects and the integrated infrared tracking system continuously captures subject's movements.

Conclusion and Outlook

Industrial virtual reality makes it possible to experience and evaluate planned work systems at an early stage. Not only can ergonomics be assessed but psychological stresses can also be ascertained by measuring heart rate variability or fatigue by electromyography. Representations in HMDs can entail severe feedback caused by the HMD's weight, cables or laptop backpack, absent natural communication, limited tracking, etc. Moreover, every subject experiences very individual feedback from poor sense of presence and proneness to cybersickness, which, in turn, heavily influences the motion and stress profiles measured. Questionnaires can help classify individual feedback.

A mixed reality approach that lessens the effect of feedback has been proposed. The Elbedome 2.0 is currently under construction and will be open for the first tests in the fourth quarter of 2017. What is more, the findings and results of the evaluation will be published. Future work will involve establishing the feasibility of projections not only on the floor but also on simplified equipment in the center of the Elbedome in order to augment the real components, thus either increasing the level of detail and improving acceptance and usability or enhancing work places with artificial contents to test and evaluate assistance systems.

References

1. Schenk, M. (2014) Industry 4.0-Wege und Lösungsbeispiele. In: Wolfgang Kersten, Koller, H. und Lödding, H. (Ed.): Industry 4.0. Wie intelligente Vernetzung und kognitive Systeme unsere Arbeit verändern. Berlin: Gito (Schriftenreihe der Hochschulgruppe für Arbeits- und Betriebsorganisation e.V. (HAB)).
2. Schenk, M.; Wirth, S.; Müller, E. (2014) Fabrikplanung und Fabrikbetrieb: Methoden für die wandlungsfähige, vernetzte und ressourceneffiziente Fabrik. 2., vollst. überarb. u. erw. Aufl. 2014. Berlin: Springer Berlin.
3. Schenk, M.; Haase, T.; Keller, A.; Berndt, D. (2016) Herausforderungen der Mensch-Technik-Interaktion für die Gestaltung zukünftiger Arbeitssysteme. In: Schlick, C. (Hg.): Megatrend Digitalisierung. Potentiale der Arbeits- und Betriebsorganisation. neue Ausgabe. Berlin: Gito (Schriftenreihe der Wissenschaftliche Gesellschaft für Arbeits- und Betriebsorganisation (WGAB) e.V, 1), S. 131–140.
4. Masik, S.; Schulze, T.; Raab, M.; Lemessi, M. (2016) Comprehensive 3D Visualization of Simulated Processes in Virtual Factories; Proceedings of The 13th International Conference on Modeling, Simulation and Visualization Methods (MSV'16)
5. Schubert, T.W., Friedmann, F. & Regenbrecht, H.T. (1999) Decomposing the sense of presence: Factor analytic insights. Presented at the 2nd International Workshop on Presence, University of Essex, UK, 6-7 April 1999.
6. Kennedy, R.S., Lane, N.E., Berbaum, K.S. & Lilienthal, M.G. (1993) Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. The International Journal of Aviation Psychology, 3:3, 203-220, doi: 10.1207/s15327108ijap03033
7. Schoor, W.; Masik, S.; Hofmann, M., Mecke, R., Müller, G. (2007) Elbe Dom: 360 Degree Full Immersive Laser Projection System; Proceedings of Virtual Environments IPT-EGVE 2007. doi: 10.2312/PE/VE2007Short/015-020
8. Landherr, M.; Holtewert, P.; Kuhlmann, T.; Lucke, D.; Bauernhansl, T.(2013) Virtual Fort Knox - Eine flexible und sichere Plattform für Engineering-Anwendungen in Fabrikplanung und –betrieb; wt Werkstattstechnik online 103 (2013), No.2, pp.146-151.
9. Otto, B.; Jürjens, J.; Schon, J.; Auer, S.; Menz, N.; Wenzel, S.; Cirullies, J. (2016) Industrial Data Space – Digitale Souveränität über Daten (White Paper); http://www.industrialdataspace.org/wp-content/uploads/2016/07/Industrial-Data-Space_whitepaper.pdf.
10. Haase, T.; Weisenburger, N.; Termath, W.; Frosch, U.; Bergmann, D.; Dick, M. (2014) The Didactical Design of Virtual Reality Based Learning Environments for Maintenance Technicians; Virtual, Augmented and Mixed Reality. Applications of Virtual and Augmented Reality, 27-38, Springer.