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Collaborative Virtual Reality System for Industrial based Assembly Training

Kollaboratives Virtual-Reality-System für industrielles Montagetraining

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Abstract: The handling of increasing product complexities and a raising number of variants demands a high degree of expertise and adaptability from employees in the assembly area. Influences such as the advancing demographic change or employee absences due to illness require the short-term assumption of assembly tasks by other employees. In order to avoid production downtimes, effective and quickly adaptable training systems must be available. Virtual Reality (VR) based simulations allow the training on a digital twin in a virtual environment. This paper describes a developed system that allows an interactive, manual assembly process. The focus is on the simulation of interdepartmental and cross-location interaction and collaboration. Additionally, a user study (N=12) was conducted to identify potential benefits of VR-based collaborative training simulations over a comparable training scenario via an online communication platform, showing that the use of the developed system results in lower assembly time and number of errors.

1 Introduction

Factors such as increased product complexity, shorter time-to-market, older workforces due to advancing demographic change and the short-term assumption of tasks by specialised employees in the event of illness or retirement from the company require the efficient training of employees to meet these challenges. The further development of modern tools for mapping training simulations is therefore becoming increasingly important (Thomas et al. 2018). One possibility that is favoured by strong technological developments is the mapping of training scenarios using Virtual Reality (VR). Simulating real environments in a virtual simulation environment, based on the three-dimensional representation of relevant products can be a useful tool for employee training. Ultimately, the goal of such simulation environments is always to establish the transfer between virtual and real environments. Workflows and previously simulated scenarios should be recognised and intuitively adopted by the user in the real environment (Learning by doing (Klemmer et al. 2006)).

In the following, the state of the art of current developments in VR-based training will be discussed. Section 3 presents a developed multi-user VR system. In addition, a user study was conducted, which aims at comparing collaborative VR training to "classical" online training. Section 4 gives an overview of the goal, procedure and results of this study. Discussion and conclusion is highlighted in Section 5.

2 State of the Art

The first VR-based training system was introduced in 1999 by Jayasekera et al. (Jayaram et al., 1999) under the name Virtual Assembly Design Environment (VADE). Interaction possibilities between user and objects were given, as well as the possibility to assemble or disassemble a product. Based on this system a large number of VR based training systems for validation, visualisation and simulation of assembly processes can be identified today (Abidi et al. 2019; Gomes de Sá and Zachmann 1999; Jayasekera and Xu 2019; Im et al. 2017). Furthermore, Al-Ahmari et. al (Al-Ahmari et al. 2016) have shown that the implementation of tactile and auditory feedback in addition to the purely visual form of presentation can increase the performance and learning rate of the user.
An increasing trend is currently seen in network-based collaboration within virtual reality environments. Bringing together multiple users within a VR environment and the collaborative handling of objects enables new possibilities in a variety of different industries. Developments and applications of collaborative VR systems can be clustered in: medical, civil engineering and industry.

Medicine: Collaborative VR simulators are already used in medical fields. Collaborative and immersive environments provide reality based scenarios for education and assessment of surgical teams. With the goal to improve medical skills, especially in rare or complicated situations multiple users can be guided by a trainer within the scenario (Chheang et al. 2019; Paiva et al. 2015; Schild et al. 2018).

Civil Engineering: With the goal of efficient and simplified collaboration between several stakeholders of a joint project, VR based environments of buildings are used. The combination with BIM (Building Information Modelling) can provide additional information regarding necessary specifications and implementations. Du et al. (Du et al. 2016) describe a system in which a common walkthrough of all stakeholders is possible.

Industry: The development of commercial simulation tools in the industrial environment is also progressing steadily. As an example, the company *Raumtänzer* (Raumtänzer GmbH 2020) offers training systems that enable a gathering of several employees in a virtual environment.

In addition, especially for industrial applications (i.e. assembly and disassembly processes), systems have to be created that enable realistic interaction between users and objects. Automated assistance, but also location-independent communication and collaboration options between several users are required. The aim of the system presented below is to simplify direct cooperation and collaboration between employees. On the one hand, a visual interaction between employees should be possible, independent of the available end devices of the users. On the other hand, the point of direct collaboration is examined in more detail on the basis of a shared digital twin. The implementation of feedback in the form of visualisation and speech should facilitate work within the virtual environment.

3 System Development

This chapter describes the developments of a VR-based system for the training of employees. Therefore, the setup and basic functionalities of the implemented user-communication and -collaboration will be described.

3.1 Setup

The setup for the virtual environment includes Head-Mounted Displays (HMD) (here: Oculus Quest). The integrated hand tracking of the HMD is used for the single-user application described in Section 3.2. On one hand, this enables intuitive handling of the application, and on the other hand, it allows to assign specific functionalities in different gestures. The multi-user application described in Section 3.3 requires at least two HMD's and the additional use of the controllers, which facilitate user interaction and movement. The system is implemented in the Unity development environment. The developments listed below build on previous implementations (Müller et al. 2020). The training environment consists of an assembly system and the product to be assembled. To give the user a realistic impression of the working environment, the workplace was digitized with the help of a 3D laser scanner. The generated point cloud was converted into an *.obj File (including necessary colour information) and embedded in Unity. For the product to be assembled (here: transmission), an existing 3D-CAD model could be used.

3.2 Network-based communication Tool for single-user Training

The functionality is divided into two modes:

- **Guided assembly**: The part/subassembly to be assembled in the next step is highlighted using a shader. In addition, a panel points to the object and provides further information regarding object name, process- and resource information.
- **Unguided assembly:** The employee does not receive any assistance and has to implement the previously learned. For subsequent validation, the throughput time and the assembly sequence is recorded.

In order to give the employee additional support, the possibility to start a video chat is given. The implementation of the chat function is based on the Agora SDK for Unity. When the video chat is started, users of the VR as well as of a computer or smartphone can join the chat room. The videos of the camera/webcam of the computer and smartphone are streamed as well as a live recording from the virtual environment. A visual and auditive communication is thus given. This functionality enables the behaviour and movements of an employee within the VR to be displayed by other devices (computer/smartphone) independent of location. Supervisors can follow the training process of a new/inexperienced employee and give him/her assistance and instructions. Figure 1 gives an overview of the communication and visualisations in the individual systems. In Figure 1 (a) the view of the user of the virtual environment becomes clear. By selecting the *Videochat*-function the user can enter the chat room. Other users are displayed next to the main panel. A similar application is provided for desktop/smartphone users. Figure 1 (b) shows the application from the PC user's point of view. The own camera image (bottom left) as well as a smartphone user (top left) and VR user (top right) can be displayed.

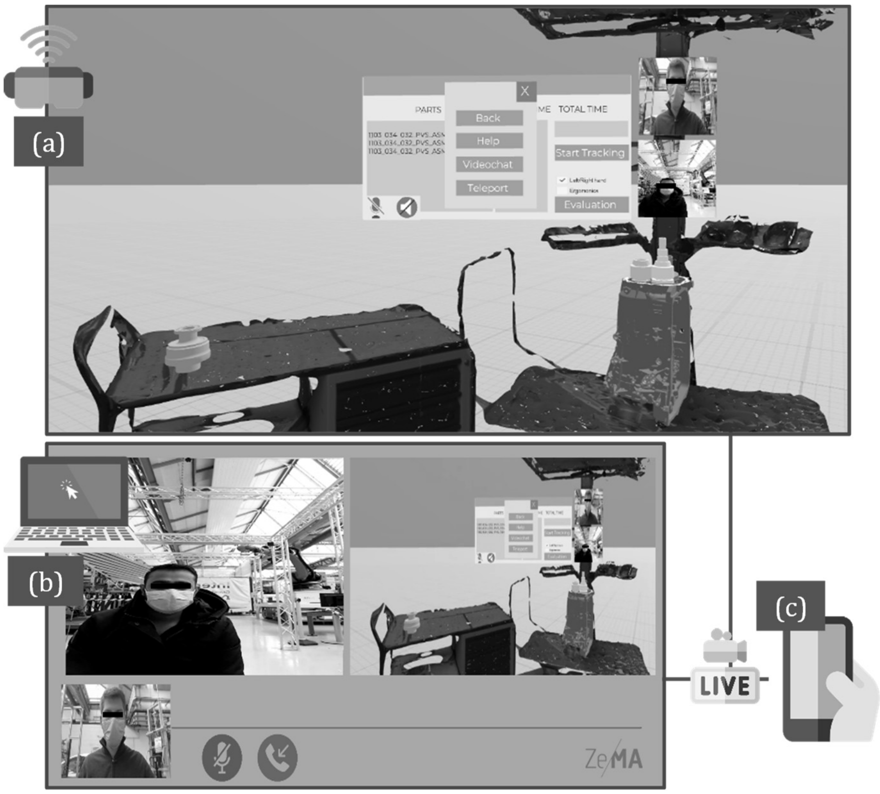

***Figure 1:** Live video chat functionality. Connection and visualization of multiple participants in (a) VR system, (b) desktop application, (c) smartphone*

3.3 Multi-User Collaboration Platform

In addition to the single-user training, a training for multi-user applications is implemented to create a virtual, collaborative environment. The goal is to enable location-independent collaboration of several employees to create an effective and efficient training character. Different functional scopes and visualisations are offered depending on a previously selected role (employee on shop floor level (worker), engineer, assembly planner, etc.). For a realistic visualisation, the focus is put on the visualisation and manipulation of objects in real time, and on the communication in the form of a voice chat. In a first step a suitable Unity extension was selected, which enables network-based collaboration. The following systems are examined in detail: Unet, Bolt, Photon Unity Network (PUN), Photon Realtime and TriCat. With regard to necessary specifications, the target system should i.e. be cloudbased, have a high number of possible users and Unity support. By performing a pairwise comparison and a utility analysis (VDI-Richtlinie Blatt 3), PUN was identified as a suitable package.

Interaction

The user/trainee should be able to interact with other users/teacher. Two types of interaction were implemented: **Voice communication** through which users can talk to each other inside the virtual environment. Provided is an open, distance and position sensitive communication. A realistic communication in which the direction of the sound depends on the position of the users to each other. Conversations at long distances appear quieter than those at short distances from each other. Furthermore, the direction from which the sound is heard depends on the orientation of the users to each other. **Tactile communication** through which users can highlight (here: via colored shader effect) grabbed or targeted parts. Instructions and assembly sequences are thus easier to see. Figure 2 illustrates the implementation of the collaborative development environment. It is shown how the interaction between a teacher (red) and a trainee (white) can take place. In point (d) of the Figure the previously presented *tactile communication* is illustrated.

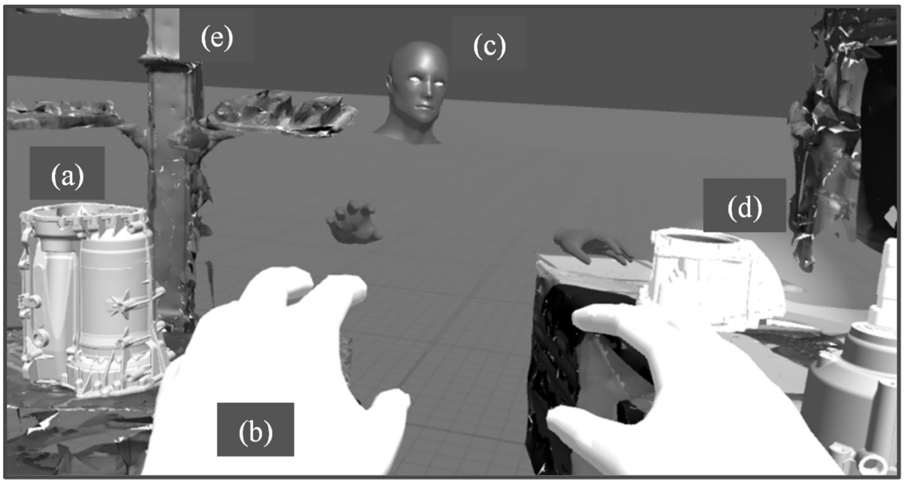

Figure 2: *Multi-user training scenario, (a) product, (b) learning employee, (c) teacher, (d) visualiszing next part by teacher (shader effect), (e) scanned real environment*

4 User Study and Assessment

In the second part of the work the developed multi-user system (see Sec. 3.3) is evaluated within a user study. The focus is on the collaboration between employees within a common environment. The goal is to make a statement regarding the effectiveness of such virtual collaboration in an industrial environment.

4.1 Experiment Task

An eight-speed automatic transmission is used to perform the user study (see Fig. 3 (c), (d)). A total of six parts/subassemblies had to be mounted by the participants. The assembly is carried out by joining. Operating resources such as screwdrivers are not necessary. In order to simulate the scenario for the participants within the VR simulation in the best possible way, the transmission and workstation were imported into the simulation close to reality. The parts/subassemblies to be mounted are placed at the same position in the simulation as well as in the real environment (see Fig. 3 (a), (b)).

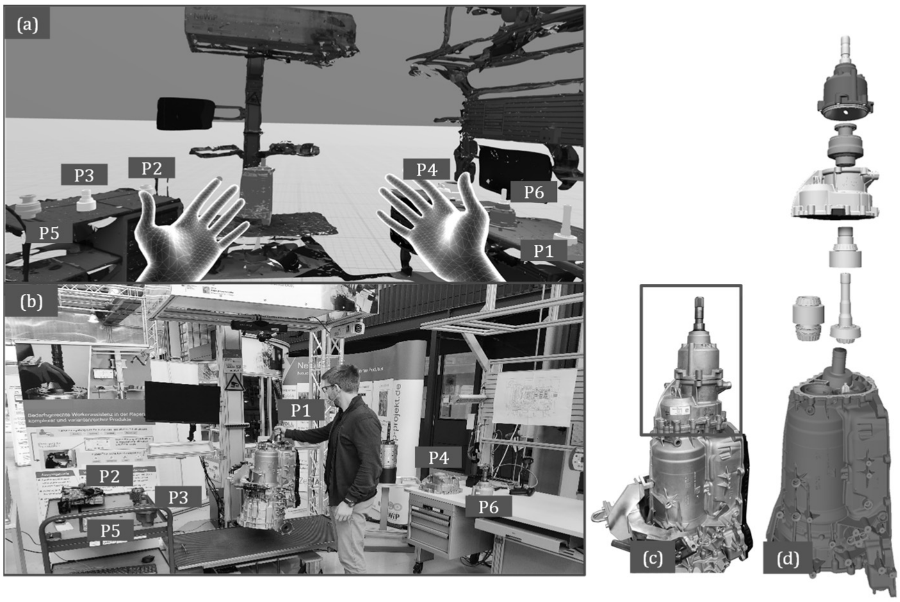

Figure 3: *Representation of a (a) virtual workstation modelled on the (b) real environment; P1-P6 illustrate the components to be assembled / Visualisation of (c) real and (d) virtual (CAD) transmission*

4.2 Procedure

To conduct the study, the participants are randomly divided into two groups. Six people per group, consisting of a mixture of men and women with technical experienced and non-technical experienced. The procedure is as follows (see Fig. 4): Both groups are provided with a declaration of consent before the start of the user study. Afterwards the participants are guided through a training session. Participants of group 1 (VR-System) receive training with the developed VR system under the guidance of a trainer. Participants in group 2 (Baseline) also received digital training. This took place using the communication tool Microsoft Teams. On the one hand, they are shown a presentation that included pictorial instructions for assembly, and on the other hand, the expert is also available for questions and explanations. After the training for both groups is finished, the real assembly took place. The time required and the number of errors made by the participants is measured.

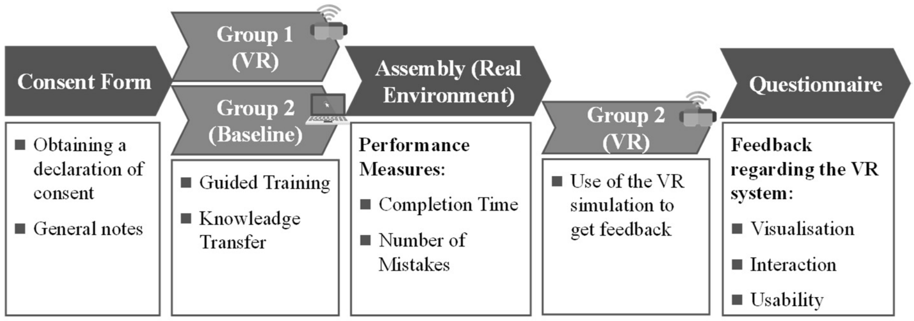

Figure 4: *Schematic process of user study*

4.3 Analysis and Results

In order to make a statement regarding the advantage of collaborative VR simulations over training processes with the help of a communication platform, two hypothesis are defined regarding assembly time and number of errors:

1. Time:

   Null Hypothesis H_0: The average assembly time achieved by both groups is equal

   Alternative Hypothesis H_1: The average assembly time achieved by participants from group 1 is smaller than the average assembly time achieved by participants from group 2

2. Errors:

   Null Hypothesis H_0: The average number of errors (two types of errors (EC) were considered here) made during the assembly process are equal for both groups

   Alternative Hypothesis H_1: The average number of errors made during the assembly process by participants from group 1 is smaller than the average number of errors by participants from group 2

Figure 5 gives an overview of the data collected during the conducted user study. Participants 1, 2, 3, 8, 10 and 12 are assigned to the group VR. Participants 4, 5, 6, 7, 9, 11 are assigned to the group Baseline. The upper part of the Figure shows a total overview of the time required, broken down into individual process times, per participant for the assembly of the transmission. The average value for the VR group is 87,17 s, the average value for the Baseline group is 121,83 s. The lower part of the Figure describes the errors made during assembly. A distinction was made between error EC1 (Wrong object gripped) and error EC2 (Mounted in wrong pose). The average values in relation to the participants of the individual groups are also given.

The calculation of the p-value (ANOVA analysis) was used to check the hypotheses previously established. The p-value describes whether the difference between the calculated mean values of several samples (VR group compared to baseline group) is statistically significant. The comparison of the p-value with a previously defined significance level (here a standard value of $\alpha = 0{,}05$ (Fisher 1992) is assumed, thus the calculated p-value needs to be smaller than α to proof statistical significance) provides an indication of whether the null hypothesis is true or should be rejected.

Table 1 gives an overview of the p-values determined and thus of the statistical significance.

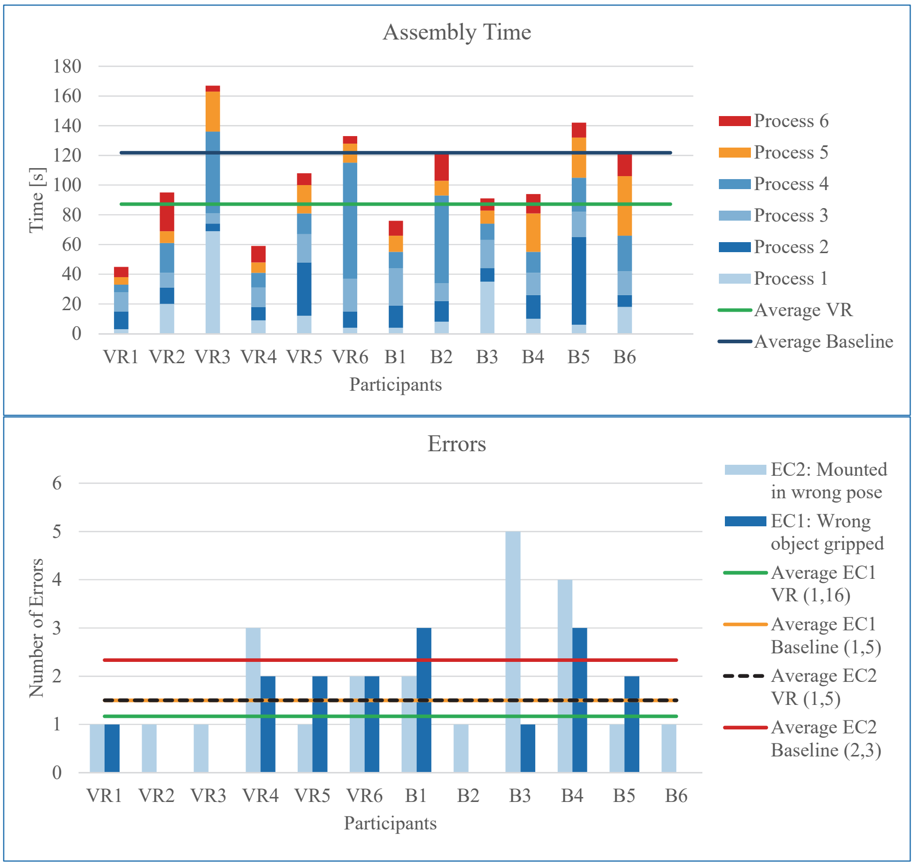

Figure 5: *Measured time per process per participant and number of errors for VR Training group and Baseline Training group (VR group participants: VR1-VR6/ Baseline group participants: B1-B6)*

Table 1: *Statistical significance*

Null Hypothesis	p-value	Significance	Null Hypothesis
Time	0,001<p>0,005	High Significance	Reject
Error – EC1	0,5<p<0,75	Low Significance	Not Reject
Error – EC2	0,5<p<0,75	Low Significance	Not Reject

5 Discussion and Conclusion

This paper presents a virtual reality based system for the simulation of manual assembly activities in an industrial environment, enabling a potential user to assemble a defined product (here a transmission). The focus was on cooperation and collaboration between employees. Furthermore, a user study was carried out to find out to what extent the collaborative VR-based system has advantages compared to a remote training via Microsoft Teams. Thereby 12 participants were randomly assigned to two groups. Group 1 received instructions within the virtual environment. Group 2 was instructed via the communication platform Microsoft Teams. With the help of an ANOVA analysis (calculation of the p value) the following conclusion could be drawn:

Group 1 participants who received virtual reality based training were able to complete the assembly of the real product in a shorter time than group 2. The average time to complete assembly operations is 87,17 s for group 1 and 121,83 s for group 2. Group 1 participant who received virtual reality based training, were able to complete the assembly of the real product with fewer errors than group 2. The wrong part/subassembly was gripped less seldom and an attempt to assemble an actually correct object in the wrong pose was made less often. Furthermore it could be shown, that VR-based training has a statistical significance in terms of assembly time compared to the baseline group, meaning that VR based training leads to a lower assembly time of the real product. Statistical significance in terms of the number of errors made could not be demonstrated. However, in order to obtain more accurate results, the number of participants should be expanded for further investigation. It could be shown that the implementation of a collaborative training form using VR technologies can bring advantages for the training or further education of employees regarding assembly processes in an industrial environment.

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