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The Creation of a Multi-User Virtual Training Environment for Operator Training in VR

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Abstract. Many industries are today heavily exposed to competition which increases the demand for continuous innovations, faster product changes and continued improvements, this is especially true for the automotive industry. Such demands raise the complexity and set a need for continuous training and development of our operators and assembly personnel to keep up with new designs and product changes. This, in combination with an aging population and a growing shortage of experienced assembly workers, increases the need for efficient training capabilities.Today most of the operator training is supervisor driven and takes place in the live production environment working with real products. This approach might introduce uncertainties and a risk to the production system as less experienced workers, still in training, might jeopardize quality, ramp ups and takt time. With the rise of virtual reality there are growing possibilities to carry out these training sessions in a more secure, non-disruptive, virtual environment without jeopardizing ramp ups, takt time or quality. This paper evaluates the possibility to introduce virtual multi-user operator training as an alternative to traditional supervised "on-site" training for assembly workers. Recreation of different assembly task from an automotive case company was created in virtual reality while introducing multi-user functionality to allow multiple operators and supervisors to observe, instruct and evaluate the performance of the operator in training. The developed demonstrator is used as the discussion basis throughout a focus group interview study with selected participants from an OEM case company and the potential of a multi-user virtual reality application as a complement for traditional operator training in operator training is discussed and future research directions for multi-user virtual reality trainings at OEMs is presented.

Keywords. Virtual Reality, Operator training, Multi-user, Assembly Training, Upskilling

1. Introduction

The automotive industry has since long been heavily exposed to tough competition that has created a demand for shorter production life cycles, higher product variant mix and increasing product complexity [1][2]. This raises the complexity for its assembly

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operators that is required to handling an increasingly fluctuating product and variant mix in a shorter time frame [3][4]. Combined with a shift in the industry towards electrification and the introduction of new technologies on the shop floor creates a huge new demand for appropriate training and upskilling applications [4].

While the need of appropriate training and continuous learning for our assembly operators is increasing rapidly, the means of training offered by OEMs is to large extent unchanged and more effective measures are needed to meet the continuous increasing demand on upskilling and training [5][3].

1.1. OEM assembly training

Continuous training of assembly operators is currently most commonly carried out in live production facilities, or in a prototype production facility. Here the operators are training on real products or on pre-series products, supported by supervisors, but with limited digital aid for guidance, instructions, and evaluation [6].

Newly employed operators undergo a mandatory course in basic skills training. This could include learning to handle relevant tools and basic safety concepts in a physical simulated factory working with dummy products [6]. Once in the production environment operators will most likely continue their training on the job, relying on coworkers, supervisors and text or picture-based instructions to complete the training of their assembly tasks [3].

This traditional approach towards operator and assembly training carried out at OEMs poses several challenges in the production systems. For instance, inexperienced operators, still in training, might disrupt the production, compromise the product quality or reduce the efficiency and lead time of the actual production [5]. Using physical facilities, tools and production for training purposes might also expose our operators to unnecessary safety risks as the task in reference might not be suitable for an inexperienced operator.

1.2. Virtual Training

To minimize challenges of traditional OEM assembly training and to minimize the non-value-added tasks of training in the live production system, a potential complement in terms of virtual training has been discussed frequently in recent publications [7]. With the use of a virtual training environment or virtual productions system operators can, with the help of virtual reality (VR), carry out their training from remote location without disrupting the live production system, and offer an environment where mistakes are without real consequences.

The benefits of training our operators in a virtual environment are thus many and has the potential to create safer training environments that minimizes the risks of personal harm, quality issues or negative effects on lead times and production efficiency [5]. It would also grant us the possibility to train our operators on tasks in potential harmful situations that can't be replicated in the real production system as well as to train on products and facilities not yet available in physical form to improve minimizer ramp ups and improve time to market [8].

A less frequently discussed aspect of virtual training in literature, is the possibility of leveraging multi-user VR applications, i.e., a VR training environment that allows for multiple operators and supervisors to train and educate each other in the same virtual environment simultaneously. A literature search in the Scopus database makes this evident, as by October 2023, only 28 out of the 348 papers with the keywords "Operator", "Training" and "VR", also includes keyword referencing to synonyms of multi-user. Meaning that current publication addresses virtual training focuses on single user and single operator training, which potentially does not meet the demand and possibility to use virtual training for tasks requiring the presence of a supervisor or the coordination between multiple operators.

1.3. Objective and aim

The objective of this paper is to understand the possibilities and application of a multi-user virtual training environments for OEM operator training. The overall research aim is thus twofold:

- Exemplify a possible methodology for the creation of multi-user VR environment for operator training purposes.
- Provide insights and discussion on the potential benefits and application areas of multi-user VR environments for operator training at OEMs.

The aspiration of this paper is to act as a guide and inspiration for similar projects to be developed and to provide discussion and future directions for the applications of multi-user virtual trainings environments.

2. Methodology

The methodology used in this paper aims to aid the general research aim in a two-step approach. Firstly, a methodology of how to achieve multi-user VR training environments is exemplified by the development of a demonstrator using said workflow. Secondly, the developed demonstrator is validated and demonstrated together with stakeholders from Volvo Cars and used as the basis of an interview study.

2.1. Demonstrator development

To be able to propose and exemplify a workflow and methodology for multi-user VR environment creation, literature was consulted to find relevant previous work. By using the keywords "VR" and "multi-user" in the Scopus database several papers with contribution in different areas of VR multi-user development were found and contributed as inspiration for the coming demonstrator development.

To be able to verify and exemplify the studied methodology for multi-user training purposes, a VR multi-user demonstrator for training was created using real use case data and training scenarios supplied by Volvo Cars. The training scenarios were recreated for the sake of the demonstrator using the *Unity Game Engine* [9].

2.2. Interview study

The interview study was conducted with two focus groups at Volvo Cars Torslanda in Gothenburg, Sweden, during September 2023. The two groups consisted of participants from two different teams involved in various steps of the development and execution of operator training. The first focus group interview was conducted with three members from the Shop Engineering team of the Casting and Machining department. Their responsibility is to develop and prepare future processes within Casting and Machining, including operator instructions and safety training for operators. The second focus group consisted of four participants from the Plant Launch team of the Final Assembly department. Their responsibility is to prepare the introduction of new products and variants, including providing hands-on training to operators. The two groups together provided a holistic perspective on operator training, from instructions and training development to actual execution of operator training in the plant.

Before partaking in the interview, each participants got to try the multi-user VR training demonstrator, experiencing firsthand the role of an operator in training using the demonstrator while being instructed on how to execute the tasks by one of the authors portrayed as the supervisor within the VR environment, see figure 1.

Figure 1. Launch Specialist from the Plant Launch team (second focus group) in the role of the operator and author in the role of supervisor, using the multi-user VR training demonstrator at Volvo Cars.

The group interviews were conducted in a semi-structured way and the participants were encouraged to discuss together and elaborate on prepared questions and topics posed by the authors. Meanwhile, the discussion was transcribed by the authors and notes were taken on the major themes and ideas as the outcome of the discussion to be further analyzed to identify themes and patterns in the and results.

3. Result - Multi-user VR Training demonstrator

In literature, several authors have previously documented similar multi-user VR application developments for various purposes. A majority of whom have discussed the use of commercial game engines and existing plugins to develop and maintain multi-user capabilities [10][11], as well as exploring prerequisites and features to elevate multi-user collaboration and interaction in VR [12][13].

With inspiration from said literature the workflow and methodology for the demonstrator was iterated and exemplified in the development of the demonstrator. This is further explained and exemplified in the sub-sections below.

3.1. Multi-user VR training environment methodology and workflow

In order to create the VR training environment and to digitalize the work instructions for training purposes the workflow considers extraction of data from the Volvo Cars PLM system, conversion and harmonizing of data and development using the *Unity Game Engine* [9]. A visualization of the applied workflow can be seen in figure 2.

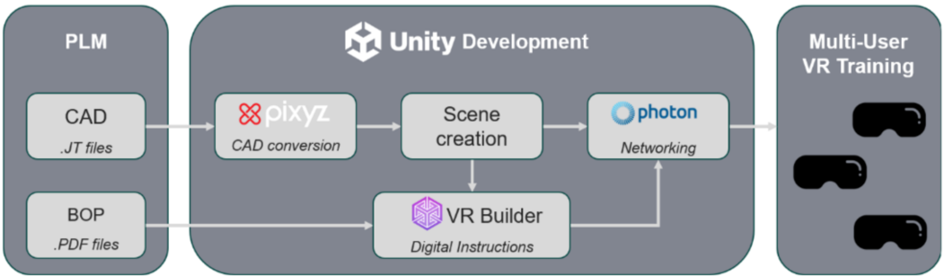

Figure 2. Workflow for the creation of the demonstrator

To represent the environment and the task in the most realistic and accurate way possible, CAD drawings of the actual parts and products to be assembled were used. These were exported as JT-CAD files directly from the PLM system of Volvo Cars. The raw CAD data exported from the PLM system carries great detail and file size, thus not optimized for VR applications. In order to make the geometry presentable and suitable for VR application the *PIXYZ* plugin [14] to *Unity* was used to optimize and convert the CAD files to a FBX file format and a file size a lot more compatible with VR visualizations. The now optimized geometry was used to create and populate the VR scene and environment in the *Unity Game Engine*.

Likewise, the assembly instructions that were used as the basis of the training activities in the VR application were exported from the PLM system of Volvo Cars as the Bill of Process (BOP), containing the required instructions. The BOP and assembly instruction sheet extracted from Volvo Cars were manually interpreted by the authors and translated into the VR environment using *VR Builder* [15], a *Unity* plugin using visual block scripting to create tasks sequences and interactions for VR instructions.

Once the VR scene and task sequence was created, the *Photon* [16] Networking plugin to *Unity* was introduced to create multi-user capability. By using *Photon* to synchronize the position and rotation of the objects in the VR scene as well as synchronizing the task execution according to the *VR Builder* block structure between all clients connected to the same server real time multi-user sessions and interactions were achieved.

3.2. Multi-user VR training demonstrator

The final demonstrator allows for up to 16 operators and supervisors to join the same training sessions in VR, and in real-time, experience the same assembly instructions while interacting in the same environment. Each person joining the VR training environment will be represented with an avatar visible to all other people in the same session. Likewise, the name of each person and their role of *Operator* or *Supervisor* is presented together with the avatar, see figure 3.

Figure 3. Avatar representing an operator in the multi-user VR training environment.

Communication between the operators and supervisors within the VR environment is enabled via proximity voice chat that allows participants to communicate freely even when joining the session from a distant and remote location.

The final demonstrator includes three different stations and assembly tasks posed to the operators in training. Each of the stations and tasks was taken from real industry scenarios and all represented three different use cases where multi-user VR training could potentially be used.

3.2.1. Station 1 – Door assembly

By following the instructions from the supervisor, the operator in training is supposed to correctly place and assemble a door panel inside of the metal car door frame. This includes picking up and placing the door panel in its correct position, attaching a cable connector on the door panel as well as entering and tightening a series of screws using a handheld screwdriver. The operator needs to rely on the instructions from the supervisor to correctly complete the task sequence. Meanwhile, the supervisor can observe and evaluate the progress and learnings of the operator. See figure 4 for an illustration of station 1.

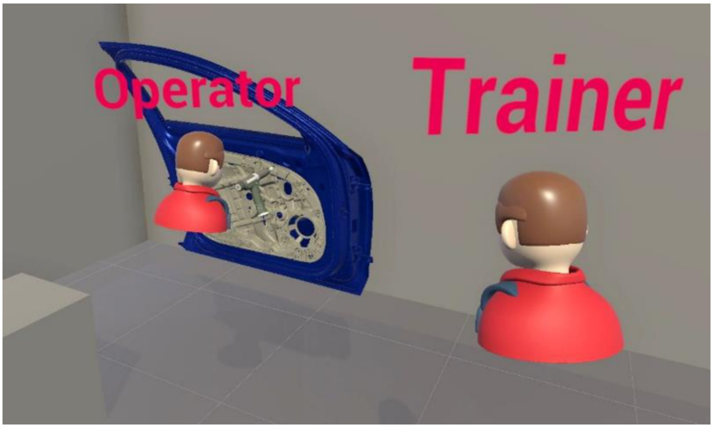

Figure 4. Station 1 visualized in the multi-user VR training environment.

3.2.2. Station 2 – Leveling sensor assembly

The leveling sensor assembly task simulates a station with two operators working together. On this station two leveling sensors are to be attached to the rear axle of a car, one to each side of the axle. By working side by side, the two operators need to simultaneously complete each side of the axle assembly before completing the task together. The operators are to train in joint task sequencing, collaboration, and tempo in order to complete their tasks. Meanwhile a supervisor is able to instruct and monitor the progress of the operators in training. See figure 5 for an illustration of station 2.

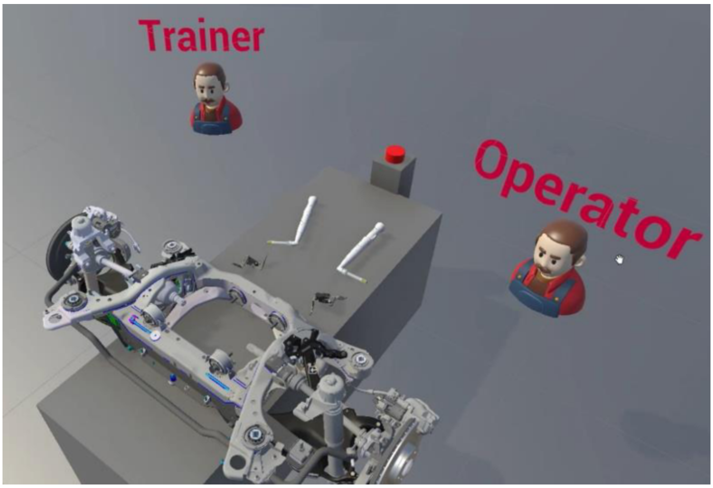

Figure 5. Station 2 visualized in the multi-user VR training environment.

3.2.3. Station 3 – Weld fixture unloading

In station 3 the task simulated is that of two operators jointly unloading a weld fixture. The part to unload is too big and cumbersome for a single operator and two operators are needed, in collaboration to lift and carry the welded part into its final position in the material rack. Here the operators are trained in mutual coordination and movement when handling objects intended for multiple operators. Meanwhile a supervisor can be present to instruct and evaluate the coordination and movements of the operators. See figure 6 for an illustration of station 3.

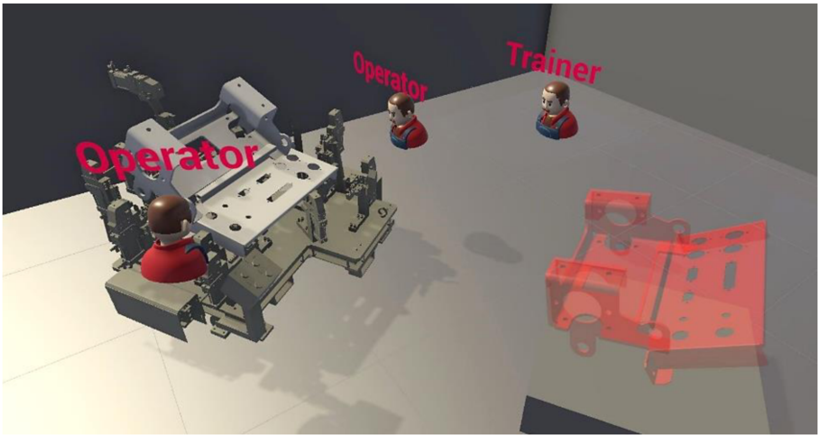

Figure 6. Station 3 visualized in the multi-user VR training environment.

4. Result - Interview study

In order the verify the developed demonstrator and to start exploring the potential of multi-user VR environments for operator training in terms of use-cases, application areas and future development, the demonstrator was used as the discussion basis for two sets of focus group interviews.

The discussions during the focus group interviews captured the participants input both on general feedback on the demonstrator and VR as a means of operator training as well as deep dived into the topic of two specific use cases identified for multi-user VR training: *(1) Supervised operator training using multi-user VR*, *(2) Multiple operators training together using multi-user VR.*

The non-quantifiable results of the discussions and key findings of the two specific use cases are presented in the following sub-sections.

4.1. Interview study results – (1) Supervised operator training in multi-user VR

The two groups of interviewees agreed that multi-user VR has the potential to boost the role and abilities of a supervisor or teacher in the context of operator training. The benefits and use cases highlighted by the interviewees in terms of empowering supervisor-based VR training has been categorized by the authors into two areas; *Flexibility and personalized learning*, *Shared virtual environment*.

There was consensus among the interviewees in the two groups that having the supervisor present in the VR environment while operators are carrying out the assembly training allows for flexible and personalized instructions suited for the scenario and individual operator. As firstly pointed out by one of the participants, it allows for interaction between the operator and supervisor, enabling questions and dialogue that might increase the learnings of the operators. This was further elaborated on by another participant in the same group, who introducing the concept of personalized adaptation of the training path and instructions given to each operator by the supervisor ability to monitor and evaluate the progress of each operator. This was compared to the fixed digital instructions or voice commands normally used in single-user VR training applications and seen as one of the strengths of the multi-user demonstrator.

The first focus group quickly identified the shared VR environment and experience between operators and supervisors as one of the core strengths of the demonstrator. Discussions among the participants unfolded on how a shared VR environment could act as a powerful visualization tool instead of video demonstrators or classroom style training. One particular scenario brought up by two of the interviewees was the ability to host virtual safety tours and safety training. The participants pointed out the ability to gather operators and supervisors in a safe virtual factory, to instruct and showcase "*do's"* and "*don't",* as a potential for improved learning and understanding of safety concerns and risks in the plant.'

On the similar topic, the participants in the second group discussed the potential of hosting virtual factory tours between supervisors and operators to increase awareness of the factory or workstation design before operators enters the plant for the first time.
However, some limitations of the supervised VR training were also discussed among the interviewees. Two of the interviewees raised the concern that the lack of physical interaction and feedback would make it impossible as a supervisor to evaluate the operators' physical ability of handling tools and tasks that require strength or motor skills. Furthermore, one of the same interviewees also deemed it difficult to evaluate the operators' tempo or stress resilience in the virtual environment as the lack of physical interaction and feedback with a real product will most likely affect the tempo and time constraints put on the operator.

Both groups concluded that supervised operator training in multi-user VR could not replace the current supervised training and evaluations in place today, but agreed that it has the potential to improve, complement or replace parts of it.

4.2. Interview study results – (2) Multiple operators training together in multi-user VR

For the second use case identified, the discussions from the two groups centered around whether multiple operators training together in a shared VR environment would contribute to improved learning.

Both the groups pointed out that the number of stations inside the plant which required multiple operators to work in collaboration is limited and thus also limits the use case for multiple operators to train together on the same station. One participant from the first focus group also pointed out that the use case of operators performing lifting or carrying tasks together (as demonstrated in station 3 of the multi-user demo), is not a crucial task and hence not the best use case for multi-user VR training. However, the participants instead raised the possibility to train on, and build awareness of, more complex and indirect collaboration between operators in the plant. The group further discussed and elaborated on the possibility of using multi-user VR training environments to teaching station- and supply dependencies by having multiple operators from adjacent or dependent stations or functions training together. Additionally, the group mentioned how multi-user VR training could be used to educate operators on the concept of standardization. As an example, they mentioned how to train operators on 5S principles [17] by having multiple operators sharing a virtual workstation they can experience firsthand what happens when tools and parts are not returned to their right designated spot or when the station is not properly maintained or cleaned by the previous operator.

Moreover, both the first and second focus group mentioned that being able to train together with other operators in the same VR environment might contribute to increased learning as operators with shared learning experience could learn from each other. One of the participants in focus group 2 also added that the shared learning experience between operators might also increase the enjoyment and the fun of the training, making it more attractive and engaging for operators which might increase their learning and engagement.

5. Discussion

The result of the two focus group interviews shows that multi-user VR environments for operator training have the potential to improve or complement existing operator training at OEMs, if applied and used correctly. Literature also shows that VR has the ability to introduce more immersive and interactive operator training without disrupting the physical production system. Multi-user VR training also has the potential to teach and improve standardization, as VR instructions eliminates the manual interpretation of traditional instructions as well as provides a safe environment to enable the possibility to train on “what-if-scenarios” and showcase “do’s” and “don’t”.

However, more efforts need to be put towards understanding when to apply VR, and multi-user VR, for operator training and which tasks or concepts that are more beneficial to train on in VR versus in a physical setting. For instance, is the best learning experience in VR achieved from repeatedly training on a correct and accurate sequence of assembly tasks? Or would intentionally introducing complexity and errors in the simulated assembly improve the learnings by introducing aspects of critical thinking and problem solving? Likewise, is multi-user VR more suitable for training operators together with hands on training and sequencing of assembly tasks [18] or is it more beneficial to use as a complement of classroom style teaching to create better awareness on certain manufacturing concepts and topics, such as safety and 5S [17]?

Once these questions have been answered and OEMs have defined clear use cases of multi-user VR training, we need to consider the scalability of the VR environment. The methodology and workflow for the development of the multi-user VR environment presented in this paper, using the *Unity Game Engine,* is arguably not a scalable approach that would enable wide adaptation by OEMs. The workflow includes manual exportation, conversion and implementation of PLM data into the VR environment as well as manual interpretations and programing of the assembly instructions into the VR environment. These are all time-consuming activities with relatively high engineering effort, creating a barrier for successful large-scale implementations at OEMs. To overcome these barriers future efforts needs to be put towards proposing simplified, and to some extent automated, VR training environment creation using commercially available platforms and software’s integrated with the existing PLM infrastructure and virtual factories of OEMs.

6. Conclusion

This paper presents a methodology and workflow of realizing multi-user VR environments for operator training at OEMs. The presented methodology was verified through the development of a multi-user VR training demonstrator which was presented and verified with stakeholders from Volvo Car Corporation. The multi-user VR demonstrator, used as the basis for two focus group interview studies, was found to be a potential complement to the existing physical operator training carried out at Volvo Cars today. The focus groups found that the multi-user VR demonstrator had the potential to bring new level of immersion and visualizations to existing classroom styled training (e.g. in safety trainings or plant demonstrations) or to create awareness of more complex collaboration and interactions between operators in the plant. The demonstrator also enabled supervisors to evaluate and monitor operators' performance and training, allowing for interaction with the operators on a new level, compared to single user VR training applications. Which enables the supervisor to assist and personalize the training when needed.

Furthermore, this paper proposes future research direction in two specific areas. Firstly, defining clear use-cases and frameworks of multi-user VR training for OEM operator training with proven and recorded value. Secondly, proposing simplified, and partly automated, VR training environment creation using commercial software and deeper integrations in existing OEMs PLM systems. This in order to overcome barriers in terms of time consumption and engineering efforts when developing new VR training material, and to pave the way for successful large-scale implementations of VR operator trainings at OEMs.

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