Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 84 (2019) 1069–1074

www.elsevier.com/locate/procedia

29th CIRP Design 2019 (CIRP Design 2019)

Virtual Reality Based Digital Chain for Maintenance Training

Manoch NUMFU[a]*, Andreas RIEL[a], Frederic NOEL[a]

[a]G-SCOP Laboratory, Université Grenoble Alpes, 46 avenue Félix Viallet, Grenoble, 38031, France.

* Corresponding author. Tel.: +33 (0)7 67 38 96 79; fax: +33 (0)4 76 57 46 95. *E-mail address:* manoch.numfu@grenoble-inp.fr

Abstract

This paper presents ongoing research about the use of Virtual Reality (VR) to facilitate training for maintenance. VR systems are now widely accepted as training platforms for complex and highly demanding training tasks. In this paper, we focus on the application of VR technology for designing and evaluating the actual training process that relates to maintenance operations. Despite the availability of increasingly many and mature VR devices, it is still difficult to achieve the level of realism needed for the effective training of particular manipulation gestures that are vital for specific assembly and disassembly procedures. We propose a systematic approach to create a VR-based experimentation environment that facilitates the selection, calibration, and evaluation of different VR devices for the training of a specific maintenance operation. We present a case study to demonstrate the feasibility of our concept, as well as the huge potential VR has to even replace the traditional physical mock-up training. Via virtual hands, users can interact directly with virtual objects via various devices (mouse, keyboard and Leap Motion). Maintenance gestures can thereby be executed as naturally as possible and can be easily recorded to prepare maintenance learning service.

Peer-review under responsibility of the scientific committee of the CIRP Design Conference 2019.

Keywords: Maintenance training design, VR-based training design, VR-based digital chain;

1. Introduction

Virtual reality (VR) is increasingly used for training purposes in industry, as VR has shown tremendous potential to revolutionize the way companies leverage knowledge and skill acquisition by their employees [1]. Virtual reality training systems are already used in a variety of domains [2]. Maintenance is a process that maintains the working condition of devices and machine to work under good conditions and safety. The heart of good maintenance is the knowledge and experience of workers. The knowledge and experience of the workers is achieved from learning session and doing by themselves. If workers use more time to learn and do their work, they would gain the experience from those activities. The legacy methods such as training manuals, job shadowing, and evaluations and certification processes are outdated, less effective, and time consuming. These methods also do not address the need to cater to different learning styles: visual, aural, verbal, etc. [3]. However, workers do not have a lot of time to train in practice because the situation and environment in the real work does not support them in learning session. The company have to pay and invest all of tools and devices in the training processes.

In this paper, we present ongoing research about the use of Virtual Reality (VR) for facilitating training for maintenance. We focus on the application of VR technology for facilitating the design and preparation of the training process that relates to maintenance operations. We propose an approach to create a VR-based experimentation environment that facilitates the selection, calibration, and evaluation of different VR devices for the training of a specific maintenance operation. This research started with the question "which devices are most appropriate for providing the realism and accuracy of gestures of training for a particular maintenance operation?" Furthermore, “how do the characteristics of that device and system impact the effectiveness of the training of the maintenance task?”

The accuracy of gestures largely depends on the good position and posture of hands while working. This is important for the training design process of maintenance work, because before the training design process is set up, we have to consider the right position and safety of hands and posture. Realism is

2212-8271 © 2019 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the CIRP Design Conference 2019.
10.1016/j.procir.2019.04.268

needed for the effective training of particular manipulation gestures that are vital for specific assembly and disassembly procedures. Usual working instructions in industry are based on a few pictures and text where the expected gestures may be hardly understood. We propose to use VR media to improve this perception.

2. Literature review

In recent years, many research papers applied AR/VR technology to improve the training of maintenance processes. Yaiza Vélaz et al, 2014 [4] used virtual reality (VR) systems for teaching industrial assembly tasks and studied the influence of the interaction technology on the learning process. They used four devices for training with the VR system on the assembly task (mouse-based, Phantom OmniVR haptic, MMocap3D and MMocap2D). Kuang Weijun et al, 2016 [5] presented a method for constructing a nuclear power plant in-service maintenance virtual simulation scene and virtual maintenance process. They demonstrate the advantage of using virtual reality technology to design and verify an in-service maintenance process of nuclear power plants compared to the conventional way. Another example in this area is presented by Nirit Gavish et al, 2015 [6]. They studied the use of virtual reality (VR) and augmented reality (AR) platforms, developed within the scope of the SKILLS Integrated Project. They assigned the VR system to four training groups in an electronic actuator assembly task. As the result of using VR system training, they empirically evaluated their efficiency and effectiveness compared to traditional training methods.

VR technology can improve the safety of working by illustrating the safety conditions required before starting the maintenance procedures. Dong Zhou et al, 2016 [7] presented a method for measuring the actual maintenance time through virtual maintenance process simulation for complex product system. They presented a method for measuring the actual maintenance time through virtual maintenance process simulation for complex product system. They proposed a corrective MOD method (Modular Arrangement of Predetermined Time Standard) to measure time and modified the initial maintenance time of each therbligs got from the virtual simulation. Virtual Reality (VR) techniques can be used in electric power systems visualization and VR can increase effectiveness of vocational training. Bartlomiej Arendarski et al, 2008 [8] applied VR and 3D visualization methods for knowledge transfer on maintenance of complex machines in electrical power systems. Franck Ganier et al, 2014 [9] said virtual reality technology opens new opportunities for operator training in complex tasks. It lowers costs and has fewer constraints than traditional training. The ultimate goal of virtual training is to transfer knowledge gained in a virtual environment to an actual real-world setting. They tested whether a maintenance procedure could be learnt equally well by virtual-environment and conventional training.

Including that many companies have applied this technology in place of traditional training. EON Reality [10] used VR technology to training in pre-flight inspections and maintenance for the plane before fly. The employees can learn quickly, remember longer and make better decision. Pixogroup [11] has deployed VR technology to train its employees on water filter replacement training. Self-training enables everyone to learn their own pace safely and effectively. Pixogroup also applied VR technology to create a multi-user training model. The model enables employees to work together in the same virtual environment, even in different locations. While employees learn with the VR training model, the employer can see and understand the skills and behaviors of employees during training. At this point, the employer can know how each employee works and how their behavior likely to be risky on work? To improve safety in the future. Heartwood [12] talked about transferring knowledge and experience from generation to generation with a safe and effective process. They used 3D simulation training model to transfer skill. In case of a 3D VRP-CH rebuild to transfer knowledge and experience. From that case study, the trainee used short rebuild time for assembly the VRP-CH model and the result also have the effectiveness of the training.

All these research studies suggest that VR technology could be applied to the training process and it could be easily understood more efficiency for learning with the appropriate tools and systems. Indeed, the previous studies do not mention the expected effect to create the training session content. One key point for a good deployment of VR in maintenance is to ease the creation of the VR content and behavior. We propose a systematic approach to create a VR-based experimentation environment that facilitates the selection, calibration, and evaluation of different VR devices for the training of a specific maintenance operation. We present a case studies to demonstrate the feasibility of our concept, as well as the huge VR potential has to replace the traditional physical mock-up training. Via virtual hands, users can interact directly with virtual objects via various devices (mouse, keyboard and Leap Motion). Maintenance gestures can be recorded and executed as naturally as possible.

3. Proposal of a VR Training Design Concept

We designed a concept by applying the VR technology to support the training process of maintenance work. Normally in the traditional training process, many company prefer using the real product over a physical mock-up training because this method is easy to set up and clearly close to real practice. However, both the availability and accessibility of the real product and equipment is typically a usual problem. Furthermore, training on real system should be avoided when we face high safety risks. We assume that VR technology support also the preparation of the training process of maintenance work, which is why we focus on the training process preparation phase.

Our Virtual Reality Training Preparation Process (VR-TPP) consists of the 4 tasks: Preparation, Execution, Implementation and Training, clustered in two phases, the preparation phase and the training phase. In this paper we focus on the preparation phase, while most state of the art papers focus on assessing the training phase. Here we propose a complete process towards training. The preparation phase consists of 2 tasks (Preparation and Execution). The Preparation task consists of 2 modules (Model preparation and Work Instruction (WI) Making), while the Execution task consists of 4 modules (Recording, Translation, VR Using and Assessment) as shown in Fig.1.

The concept of WI making is to invite the maintenance expert to produce and reproduce gesture within a VR environment.

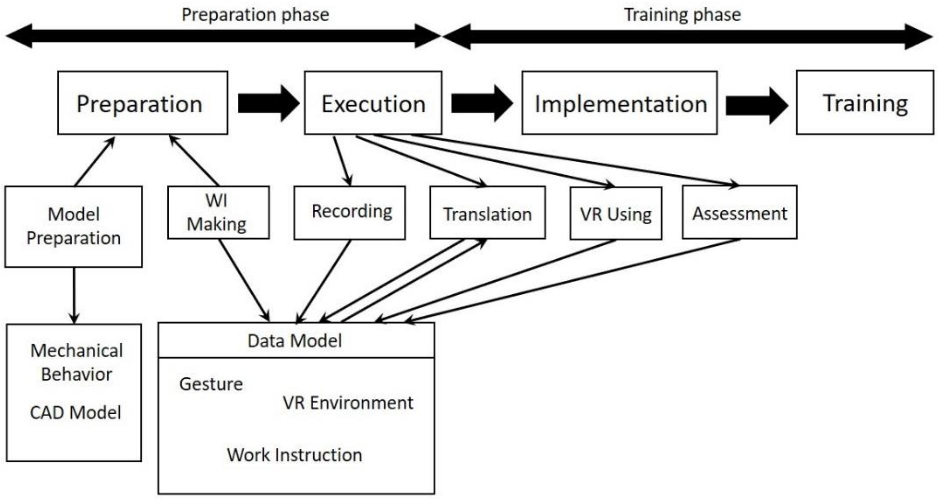

Fig. 1. The systematic approach of Virtual Reality Training Preparation Process (VR-TPP).

The VR-TPP environment is decomposed into several modules. We need a data model which manages the information shared for all the other modules. While VR is used for training session, here the originality is to use VR also to track real gestures and to prepare the training content. Depending on the nature and difficulty of the gesture necessary for maintenance (disassembly, repair, re-assembly), the concept allows for different devices to be evaluated. Various tracking systems for fine gestures exist (e.g. mouse manipulation, Leap Motion, data glove, IR tracking system as well as real sense accelerometer). Almost all these systems require global positioning which is invasive in industrial context and not efficient because of potential occlusion. It is therefore hard to record the expert gesture in a real workshop. Consequently, the idea is to invite the maintenance expert to reproduce gesture within a VR environment. The main benefit of this is to avoid occlusion. The key challenge is to support VR maintenance realistic enough for fine and realistic gesture repetition.

3.1 Preparation task

The Preparation task consists of 2 modules (Model preparation and WI Making). It is used to define and create the CAD model, the mechanical behavior and work instruction. This task also is used to input the model data into VR-TPP and environment.

3.1.1 Model Preparation

The model preparation module is used to define the mechanical behavior of part in maintenance content and CAD model (3D model). This module also describes the relation of parts in the maintenance context. Importing the 3D models to VR environment, usually we created the 3D models with an Autodesk Inventor software and exported those 3D files to the VR environment by OBJ format or any others standard.

3.1.2 WI Making

The Work Instruction (WI) making module describes the process and sequence of maintenance work.

Then, we design the process of maintenance work and test it on VR-TPP. While user operated on that work we can see and know which process should be changed or modified by comparing with the original process from maintenance expert.

3.2 Execution task

The execution task is also part of the preparation phase; it is used to operate the VR-TPP. This task consists of 4 modules (Recording, Translation, VR Using and Assessment).

3.2.1 Recording

The recording module is used to record the data from VR environment (posture of gesture and position, operation time). The posture of gestures and position are recorded 3D animations and can be replayed at any time. Users see what they do during the maintenance work with VR-TPP. The operation time is recorded while the user carries out the maintenance work.

3.2.2 Translation

The Translation module is used to change the technical data to program data and translate that data to simulation media. This module is also used to translate numerical results to graphical displays.

3.2.3 VR Using

The VR Using module is used to connect to VR-TPP and devices. In this paper, Leap Motion device, mouse and keyboard are used for test. User can interact with VR environment on VR-TPP and receive the immersive through those devices.

3.2.4 Assessment

The assessment module enables assessing the ease of using of VR devices and the realism of VR training. While users operate on the VR-TPP, they can receive both of active and passive information. The active information is physical interaction by using devices. Users can recognize the physical reaction while they work on the VR training. Every device might not fit to all people. However, we are looking for the devices that are most appropriate for a specific maintenance work. The passive information is visual interaction by watching the media. User can recognize the realism level with the VR display. The realism is depended on the level of technology.

3.3 Implementation task

The implementation task is part of the training phase. This task is used to implement the VR-TPP after preparation phase. In the preparation phase, we design and assess the VR training program with VR-TPP. In the training phase, we will set the VR training to the real training process and implement that program to standard. We will elaborate on this task in future publication.

3.4 Training task

The training task delivers the benefit and efficiency of VR technology for training by comparing it with traditional training methods. In Fig. 2, we designed the comparison method between practice with traditional training method and practice with VR-TPP.

As first step in this paper, we focus on the VR Using and Assessment module in the preparation phase. We used this concept to investigate a case study, which we will present in the next section.

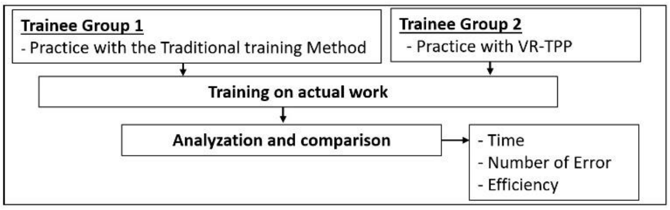

Fig. 2. The comparison method between practice with traditional training method and practice with VR-TPP.

4. Case study and discussion

We aim at validating VR-TPP in a case study to demonstrate its potential to design and assess the repairing process of a saw blade. We expect that VR preparation training method can replace the traditional physical mock up training. The demonstration was created on PC computers (Processor: Intel (R) Core (TM) i7-4750HQ CPU @ 2.00GHz (8 CPUs), ~ 2.0GHz, Memory: 16 GB of RAM, and NVIDIA GeForce GTX 950M: 4 GB of graphics card). The VR environment created on Unity software and simulated on a 2D Desktop PC for repairing a saw blade as shown in Fig 3. A Leap Motion device is used for choosing and placing the parts. Hence, the user can see a virtual representation of their hands on the desktop PC. The parts on the scene can be selected and removed by virtual hands. Our setup uses two kinds of controllers for controlling the movement of the view point. The mouse moves the camera in order to look at the working area and around it in the virtual environment. The keyboard is used to move the direction of camera to left-right and front-rear.

We use this approach to design and evaluate a work instruction (WI) before creating an operational manual. Usually, a WI is designed from the real situation, it has many conditions as we mentioned above. The main condition is about safety and danger in work. We tested this approach with the VR-TPP concept with 10 people to demonstrate how VR-TPP can design and valuate the training process in training preparation phase. The trainees have to disassemble the saw blade out from the jigsaw in the VR environment without prior knowledge of how to capture and remove the saw blade.

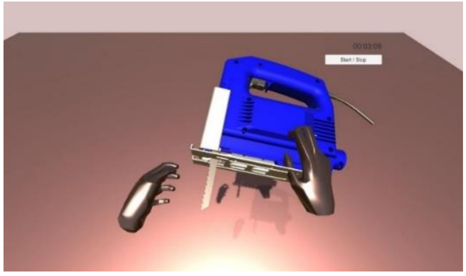

Fig. 3. Repairing a saw blade by virtual hands.

From the test result, we found that we can summarize how to remove saw blade from jigsaw in three methods from the group of trainees. First method, the trainees moved their hands to hold the saw blade directly from the front of cutting edge side. Second method, the trainees moved their hands to hold the saw blade directly from the bottom of sharp side and third method, trainees moved their hands to hold the saw blade directly from the back side of saw blade as shown in Fig. 4.

From the methods we captured, we considered with the expert which method is appropriate and we described why we selected it. The appropriate method was the third method because we can see that the first and second method will cause injury with trainees when they use those methods to practice in real situation as shown in Fig. 5 and Fig. 6.

From the demonstration, we can use this concept with a complex and dangerous maintenance work. The VR-TPP concept will be able to design and assess the training process more easily, especially in terms of safety as well as we can reduce the process of locations preparation, tools and equipment for actual testing.

In order to be able to assess the appropriateness of the devices chosen, we also observed and inquired information from trainees about perception levels in the VR environment. These figure can help to explain how much the chosen VR environment is suitable for the purpose of close-to-real maintenance training, and were the weaknesses are located.

In order to capture related indicators, we created a questionnaire, containing questions in the following three categories: perception level for the ease of the operating job, the ease of using the tools as well as the perception level for the realism.

The ease judgment level for operating job could be selected from five levels per step (very easy, easy, normal, difficult and very difficult). Trainees can also describe the difficulties they are facing during a particular operation in the VR environment training. For the ease of using tools, we separated the level of perception of using the three devices (keyboard, mouse and Leap Motion). Each device can be rated using the same 5-levels scale. Finally, for the perception level in realism, we focused only the visual perception level (since we did not use haptic feedback yet), rated using the scale shown in Table 1.

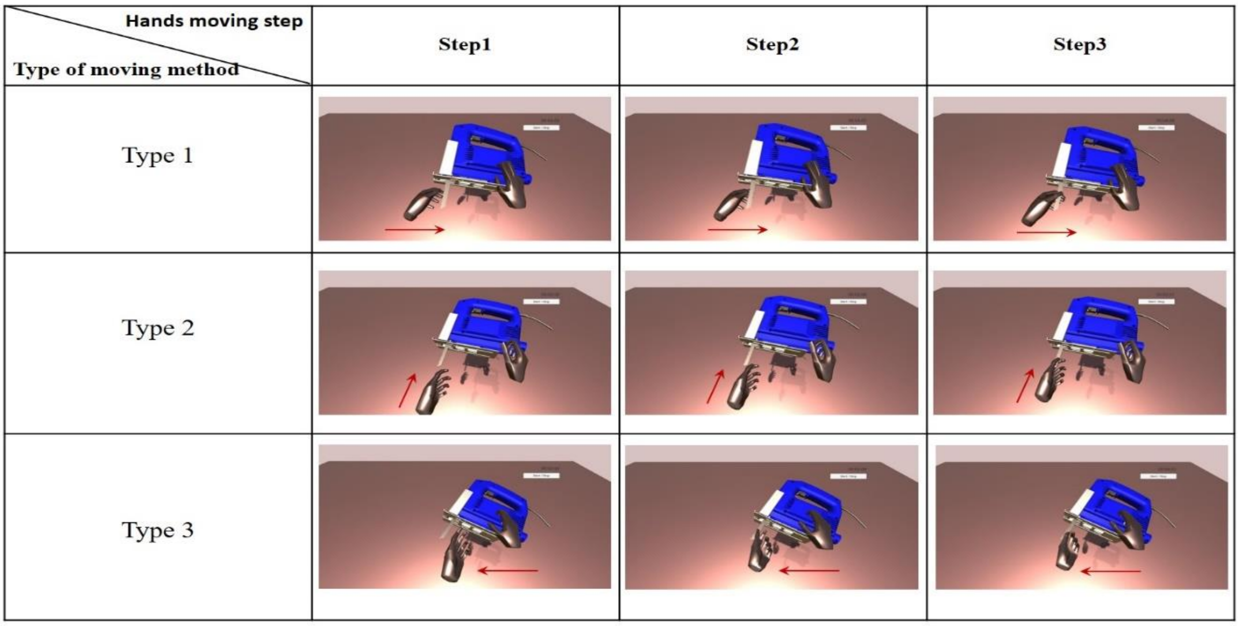

Fig. 4. The hands moving method.

From the observations and test results, we found that the perceptions level for the operating job is quite difficult to use. The trainees felt that the distance between the part and the hands does not correlate sufficiently well with reality. Especially, they felt losing the perception of touching (which is mainly due to missing haptic feedback and stereoscopy). With the VR hands it is also difficult to catch and work with the small parts in the relatively narrow space of the Leap Motion device.

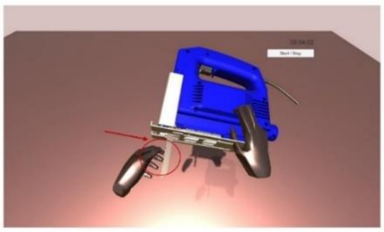

Fig. 5. The injury cause from trainees move their hands to hold the saw blade directly from the front of cutting edge side.

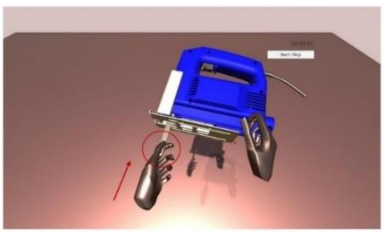

Fig. 6. The injury cause from trainees move their hands to hold the saw blade directly from the bottom of sharp side.

To use all the tools at the same time is quite difficult. Trainees were confused about how to practice and control each of them (keyboard, mouse and Leap Motion) in the scene as the same time. On the other hand, they understood well how to use those tools alone as shown in Fig. 7.

As for the perception level of realism, most trainees have perceived only a bit of realism, mainly due to the missing haptic feedback. It means that 2D display technology is not good for this VR training.

Table 1. The table of perceptions level.

Perceptions level	Description
1	I have not perceived the level of realism.
2	I have perceived a bit of realism level.
3	I have perceived the realism level close to reality.
4	I have perceived the realism level as the same level of reality. (Perception is at the same level as working in a real location.)

This result was expected, and therefore only served us in order to demonstrate the potential of the VR-TPP as a whole: as it clearly decouples the creation of models, work instructions, training environment setup and evaluation, we have the possibility to test and evaluate a variety of devices and rate their performances against the same criteria. From this, we can also build a data base about experiences and evaluations per device and/or setup and set of gestures, thereby establishing a knowledge base for the computer-supported selection of the VR devices/environment that are most appropriate for a particular training task.

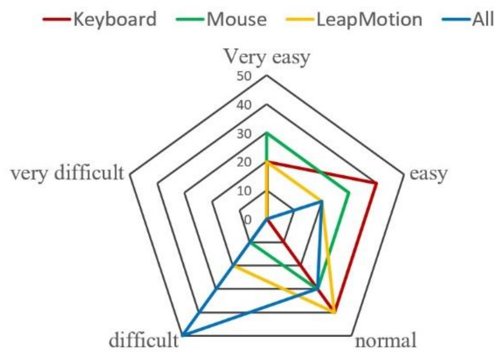

Fig. 7. The percent of users for perception level of using tools

This first experience demonstrated that using virtual technology in the preparation phase of the training process will have much more interest in the next research step that will deploy stereoscopy and haptic devices.

We are investigating the concept of VRTPP whether it can be applied in the process of training preparation before the training process. We have tested by using VR technology in non-immersive VR level [13]. In the near future, we plan to develop into Fully-immersive VR level by focusing on the use of VR technology to capture the gesture and position of hands in the process of training preparation. This information will again be used to improve and re-design the gesture by inviting experts to participate in the consideration process.

5. Conclusion and future work

In this paper we specify the concept of a VR-TPP to be used for both preparing and executing VR maintenance capturing and training sessions. We use VR tools for capturing expert gestures and storing this information with a working instruction module, which is also part of the VR-TPP environment.

The result from the case studies shows that the technology of devices is important to capture fine gesture. Despite, Leap Motion device's capability of capturing and showing virtual hands in the VR environment, it also has the limitation of space using and it cannot respond to the fine gesture when we use in the big area.

This research is a beginning process which is used to create a design process and create work instruction with VR technology. Our VR-TPP concept and environment shall leverage the identification of the appropriate VR tools and approach providing the ability to train maintenance operators. In addition, we will invite maintenance experts to test and re-produce the work instruction in the VR environment. We created a concept and tested our concept with the VR-TPP as shown in the case study. The working instruction of the model can be re-used for maintenance training in various formats, from classical paper instruction, to complex VR training modules, passing through simple video preparation. The main benefit comes with the fine gesture capacity which make sense because we avoid occlusion issue.

Our future work, we must continue to work to find out which device or system will be appropriate and could be applied to design and evaluate the actual training process related to maintenance work. We have identified several open questions about devices and technology. We will also examine other devices and system of VR technology for tracking the hands and body movement. Since tracking quality is hardware dependent, we aim at investigating which tools and hardware are most appropriate and efficient for specific training creation tasks based on our VR-TPP concept.

We plan to expand our work area with the Optitrack IR capture system. We also plan including haptic feedback devices in the training environment in order to give better guidance to the trainee when executing the training tasks. We will improve the content and virtual environments that are as close to the real work as well as raise the level of VR immersion.

References

[1] Alejandro Dinsmore. VR Training Development in Four Steps. https://www.learningsolutionsmag.com/articles/vr-training-development-in-four-steps. Accessed 30 October 2018.

[2] Ragan, E. D., Bowman, D. A., Kopper, R., Stinson, C., Scerbo, S., & McMahan, R. P. (2015). Effects of field of view and visual complexity on virtual reality training effectiveness for a visual scanning task. IEEE Transactions on Visualization and Computer Graphics , 21(7), 794–807.

[3] SHELBY HEGY. How AR and VR are transforming training in manufacturing, AUGUST 9, 2018. https://www.controleng.com/articles/how-ar-and-vr-are-transforming-training-in-manufacturing. Accessed 27 March 2019.

[4] Yaiza Vélaz, Jorge Rodrıguez Arce, Teresa Gutiérrez, Alberto Lozano-Rodero and Angel Suescun. The Influence of Interaction Technology on the Learning of Assembly Tasks Using Virtual Reality. Journal of Computing and Information Science in Engineering, DECEMBER 2014, Vol. 14 / 041007- Pages 1-9.

[5] Kuang Weijun, Yu Xiao and Zhang Lin. Research of Nuclear Power Plant In-Service Maintenance Based on Virtual Reality. Journal of Nuclear Engineering and Radiation Science, OCTOBER 2016, Vol. 2 / 044507-Pages 1-6.

[6] Nirit Gavish, Teresa Gutiérrez, Sabine Webel, Jorge Rodríguez, Matteo Peveri, Uli Bockholt and Franco Tecchia. Evaluating virtual reality and augment reality training for industrial maintenance and assembly tasks. Interactive Learning Environments, 2015, Vol. 23, No. 6, Pages 778–798.

[7] Dong Zhou, Xin-xin Zhou, Zi-yue Guo and Chuan Lv. A maintenance time prediction method considering ergonomics through virtual reality simulation. SpringerPlus (2016) 5:1239, Pages 1-22.

[8] Bartlomiej Arendarski, Wilhelm Termath and Paul Mecking. Maintenance of Complex Machines in Electric Power Systems Using Virtual Reality Techniques. Conference Record of the 2008 IEEE International Symposium on Electrical Insulation, Pages 483-487.

[9] Franck Ganier, Charlotte Hoareau and Jacques Tisseau. Evaluation of procedural learning transfer from a virtual environment to a real situation: a case study on tank maintenance training. Ergonomics, 2014 Vol. 57, No. 6, Pages 828–843.

[10] EON Reality Team. Aviation Maintenance Trainer. https://www.eonreality.com/portfolio-items/aviation-maintenance-trainer. Accessed 11 October 2017.

[11] Bill Rice. THE FUTURE OF SAFETY TRAINING ENHANCED BY VIRTUAL REALITY. September 22, 2017 - VR Training. https://pixogroup.com/virtual-reality-future-safety-training. Accessed 23 October 2017.

[12] Raj Raheja. Use 3D Simulation to transfer skills from Boomers to Millennials. https://hwd3d.com/blog/3d-simulation-transfers-skills-boomers-to-millennials. Accessed 24 October 2017.

[13] T.S. Mujber, T. Szecsi and M.S.J. Hashmi. Virtual reality applications in manufacturing process simulation. Journal of Materials Processing Technology 155–156 (2004), Pages 1834–1838.