Research Article

Virtual Reality Technology for Maintenance Training

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Abstract
This paper is part of a bigger research project that aims at establishing an integrated VR environment for preparing, evaluating, and executing maintenance training in virtual environments. In order to apply the virtual reality technology to maintenance task training, this paper presents a Virtual Reality for Training in Maintenance Task (VR-TMT) platform using the simulation of the process of a gearbox disassembly and assembly as an example. The system setup and configuration are presented in detail, as well as the analysis of the experience, perception level and side effects of using VR devices. The results show that the user experience and perception levels on provided by the VR-TMT platform are on a good level. In addition to that, the VR-TMT system is easy to use, understand and flexible for transport. Users can therefore profit from the VR-TMT platform to train anywhere and anytime according to their needs. The majority of the experimental users experienced only few side effects, in particular both physical and visual tiredness. However, the experiment confirmed that the immersive experience of VR-supported maintenance task training outweighs the reported side effects.

Keywords: Virtual reality technology, Virtual reality based training, Maintenance training, Virtual environment

1 Introduction

Virtual Reality (VR) technology is increasingly used for training in industry, as VR has shown a tremendous potential to revolutionize training by replacing real-world training by training in a virtual environment. Virtual reality technology is already used in a variety of domains such as advertising, medical, education, manufacturing, and design. Industrial maintenance is the process of maintaining the satisfying and safe working conditions of devices and machines over their lifetime. At the very heart of good maintenance is the knowledge and experience of workers. Workers achieve their knowledge and experience of workers through training and doing maintenance tasks themselves. However, in general they do not practice enough and they need training because their situation and environment do not support them [1]. In particular, dangerous and huge maintenance tasks are difficult to practice. In addition to that, the continuously rising density and complexity of mechanical parts and assemblies makes maintenance tasks increasingly difficult and hazardous [2]. The traditional training method such as training manuals, job shadowing, classroom and workshop training appear therefore more and more often not efficient enough anymore.

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Some groups of industries operate 24 hours a day without stopping machines. Some factories, such as sugar factories and tapioca starch factories [3], operate throughout the year without halting machinery for extremely long periods of time. For this reason, the maintenance staff have hardly any occasion of practicing and learning how to maintain and repair these machines. This is a huge problem in particular for new employees. Manipulating the real machinery without experience is also likely to provoke breakdowns and accidents with potentially serious consequences on health, ecology and economy. In order to address these problems, we propose virtual reality technology following a novel concept that facilitates the preparation, execution and evaluation of VR training tasks.

In our previous work [1], we have specified the concept of a VR-TPP for preparing, executing and evaluating VR-based maintenance training sessions. We use VR tools for capturing expert gestures, and we record the working process using VR facilities. The work presented here builds on this concept and focuses on the user experience evaluation when using the platform for a particular maintenance task. In addition to that, we assessed the perception level and side effects of using VR devices for this kind of training.

We present our contributions in the following structure: Section 2 discusses about related work. Section 3 presents an overview of the "Virtual Reality for Training in Maintenance Task" (VR-TMT) system and, Section 4 discusses the experiment and result. Finally, section 5 gives an outlook to plan future research activities.

2 Related Work

There is a lot of research trying to apply virtual reality technology for maintenance tasks [4]–[9]. Furthermore, virtual reality technology can open new opportunities for operator training to complex tasks. Ganier *et al*. [10] show that a maintenance procedure could be learnt equally well by virtual-environment and conventional training. Both training types (conventional and virtual) produced similar levels of performance when the procedure was carried out in real conditions, while the virtual training lowers costs and has fewer constraints than traditional training. In addition, Weijun *et al*. [11] also presented 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. Lin *et al*. [12] describe an architecture of virtual reality-based training systems (VRTSs) and a knowledge modelling approach to designing VRTSs. They applied this system in the CNC operations training. Vélaz *et al*. [13] use 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 tasks (mouse-based, Phantom OmniVR haptic, MMocap3D and MMocap2D) to study the efficiency and effectiveness of each interaction technology for learning the task. Furthermore, many companies are also interested in VR technology to replace traditional training. Raheja [14] used 3D simulation training model to transfer skill. 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 easily lead to more efficiency for learning if the appropriate tools and systems are used. For this research, we have chosen a fully immersive VR approach based on an easily accessible low-cost VR equipment.

3 VR-TMT Overview

In this section, the devices, models and techniques exploited in building the VR-TMT application are described. The system configuration is presented in detail, as well as user interaction.

3.1 *Maintenance content definition*

Content creation will be determined based on the needs of the customer or user who wants to create training courses with virtual technology. The virtual environment shall resemble the actual environment appropriately, including working conditions and procedures. This particular demonstration is the simulation of disassembling and assembling a gearbox to demonstrate the ability of virtual technology in the maintenance task. For this, a virtual factory environment has been built on a fully-immersive VR level [15], so that users can perceive the highest level of immersion,

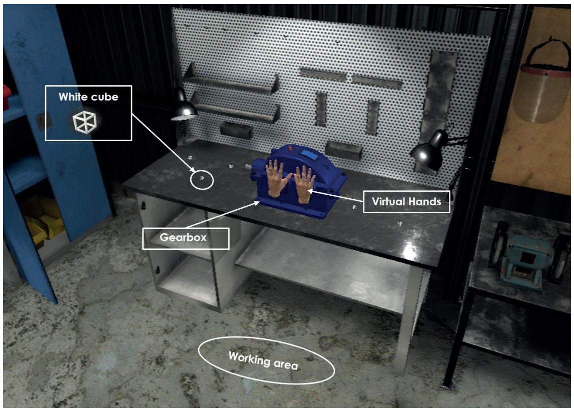


Figure 1: The small virtual factory simulation containing the main virtual components.

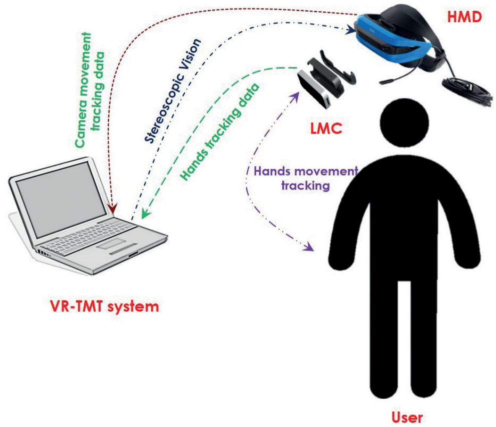


Figure 2: System setup and configuration.

as shown in Figure 1. In order to dis/assemble the gearbox, the working area is positioned at the front end of the table. It is necessary to place those parts at the position of a white cube. User can choose to place according to the position of the white cube as shown in Figure 1.

In the process of disassembly, if user removes the parts and move it closer to its docking position (white cube), the parts will be placed and positioned automatically. In the process of assembling, if users move the parts closer to the right assembly position, the parts will be positioned at the same position automatically as well. With this content, users can practice anytime according to their needs for increasing their skills and experience.

3.2 *System configuration*

The VR-TMT system has been developed on the Unity 3D game engine that can be executed on a typical PC running the Windows operating system. Our particular system platform for this experiment consisted of a laptop running Windows equipped with NVIDIA GeForce GTX 950M graphics card, ACER Windows Mixed Reality HMD, Leap Motion Controller (LMC), keyboard and mouse. The LMC was installed in front of the Head Mounted Display (HMD), and the devices were connected to the PC over USB cables and HDMI. The communication between the Unity platform and the LMC was implemented using a C# program language script. Figure 2 shows a system diagram as well as the data flow between the PC and the devices.

The virtual workshop was imported from a commercial package developed for Unity software. However, the 3D models of the parts that we used were created with CAD software and imported in Unity in ".obj" file format.

The Unity game engine was used for assembling, disassembling, rendering, lighting, shading, physics and collision modelling, simulation and programming, while the LMC sensors were used to track hand movement and send the data back to the program for creating the virtual hands in the virtual environment. Users can use these VR hands to handle and position the work piece.

3.3 *Virtual environment*

During training on the VR-TMT platform, users must wear the HMD and stand in front of the laptop at a distance of 0.3–0.5 m. The virtual environment is displayed in real time with the HMD screen. The calibration of the virtual hands is done by the user raising both hands in front of the HMD screen which has the LMC installed, so that the system will detect and display the virtual hand in a VE. After calibrating, user can walk around in the real space to discover the virtual environment in an area of approximately 1.5 square meters, due to the limitation of cable lengths of HMD and LMC. While the user rotates and moves the head, the camera will display the image on the HMD screen in the first person view, which is like the own human eyes' view.

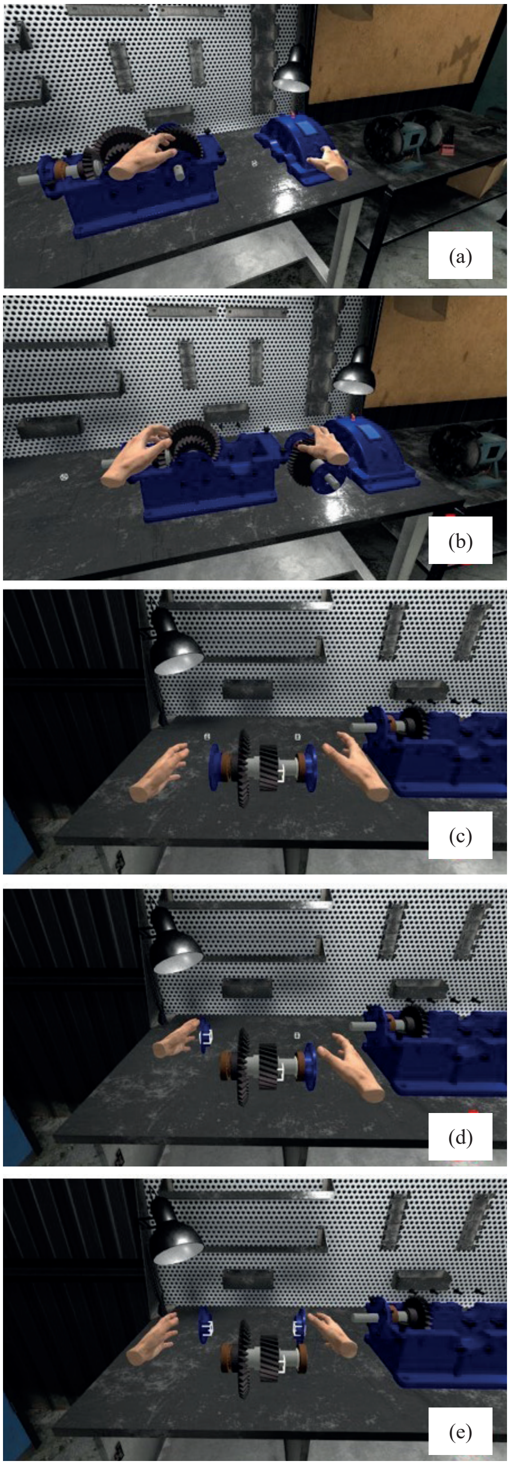


Figure 3: A storyboard displaying the different tasks of the working process.

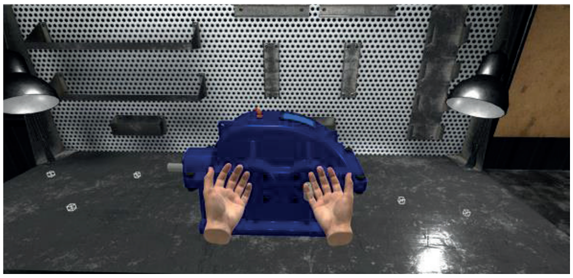


Figure 4: Virtual hands as created by "Core" of leap motion.

In this particular experiment, trainees were asked to disassemble a gearbox by separating five pieces from each other. The disassembly process starts with (a) removing the cover and placing it on the table; (b) removing the gear set and placing it on the table; (c) moving the gear set to the maintenance area; (d) removing the front bearing support cover and placing it on the maintenance position; (e) removing the rear bearing support cover and placing it on the maintenance position as shown in Figure 3. The whole process was recorded as image sequences. Then the users were asked to reassemble those parts to a gearbox.

3.4 *Creation platform*

This platform is built on a commercial software utility is called "Unity". Unity is a cross-platform game engine for the development of 2D and 3D video games, including the creation of simulations on computers (both desktop and laptop), consoles, smart TVs, websites and various portable devices. Unity uses C# as the primary language for developing games on the engine. Moreover, Unity Script, a language similar to JavaScript was used [16]. Components and scripts are installed in the GameObject to define and control the behaviour of the GameObject and all the objects within the virtual environment. Scripts are important parts for treating the input values.

A useful Unity asset type is the Prefab. Prefabs are instances of a GameObject, cloning the complete original one with its components and its properties. Any changes made to a prefab are immediately applied to all its instances. The advantage of Prefabs is that they are re-usable and they can be easily instantiated or destroyed throughout the runtime, shown in Figure 4, was created by "Core" of leap motion with a few

Figure 5: User interacting with the VR-TMT system.

lines of code. In the scenario implemented composite patches creation, selection and placement were implemented with prefabs [17].

3.5 *User interaction techniques*

In VR, the interaction technique is the method to link between software and hardware. In addition, this technique used to interact between VR-TMT platform and user. The typical generic interaction tasks of VR-TMT platform are the following: selection (grasping and placing), manipulation and system control. In selection (grasping and placing) technique is installed with a leap motion package, called an interaction engine as described in the previous topic. Interaction engine is composed of an interaction manager (IM) and an interaction behaviour (IB) script. Each script is used to control the objects in VE. The IM script used to link between devices and system, while the IB script used to define behaviour of the objects in VE. Furthermore, the IB script must work with the Rigid Body (RB), Mesh Collider (MC) and Mesh Render (MR) in order to interact between objects and virtual hands.

In display mode and system control of VR-TMT platform is adjusted via 2 systems, either the 2D desktop or the 3D fully immersive with HMD as shown in Figure 5.

The mode selection takes place at the beginning step by changing the platform on Unity software between the PC platform and Universal Windows platform (windows mixed reality technology). The installation and connection of software and all devices will be configured similarly on both of them (2D desktop and 3D fully immersive with HMD). However, the display mode and system control are different. The 2D desktop mode simulated the result on 2D screen and this mode can manipulate camera view and movement by mouse and keyboard, while the 3D fully immersive with HMD mode uses sensor which is attached with HMD glasses. The interaction between the user, the devices and the system is shown as an activity diagram in Figure 6.

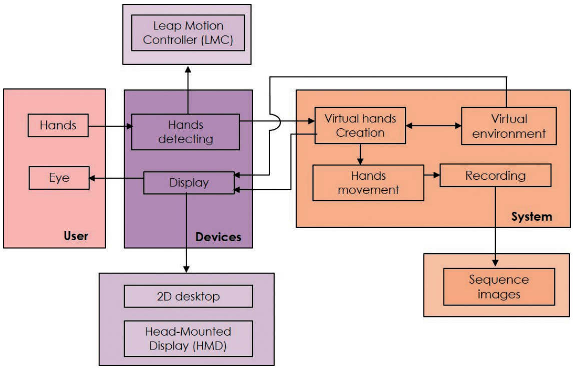


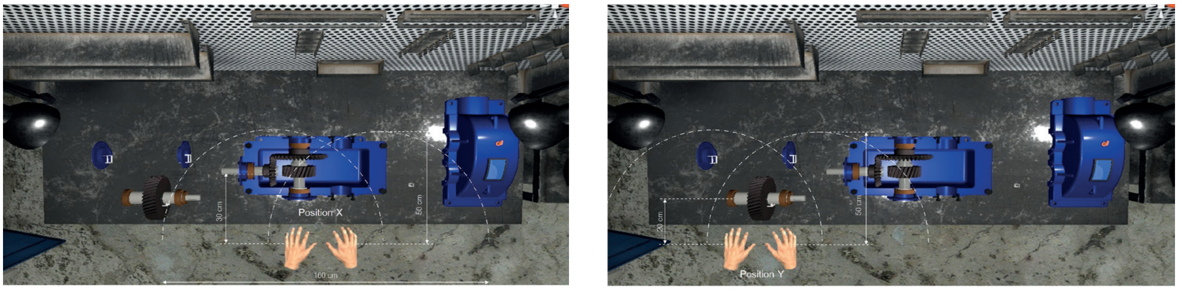
Figure 6: VR-TMT activity diagram.

As for the limitation, the VR-TMT platform has a limitation distance of hands movement detecting of LMC. Due to the LMC area where its detects the user hands: only about 250 mm above the controller [18].

4 Results and Conclusions

A group of 27 industrial engineering students (11 males and 16 females) were asked to perform the described task in the VR-TMT system. An average age of participants were 21 years (SD = 1.76 years). The youngest was 18 and the oldest 25 years old. From these 27 students, 19 were left handed, 8 participants right handed, and 1 of the latter was ambidextrous (i.e. both right- and left-handed).

In this experiment, the participants were asked to operate on the process A and B at the X position and operate on the process C, D and E at Y position as show in Figure 7. Only the participants' hand motion characteristics were recorded in the virtual environment and resulted in image sequences like the one shown in Figure 8.



(a) (b)

Figure 7: Working environment in VE (a) Working on position X, (b) Working on position Y.

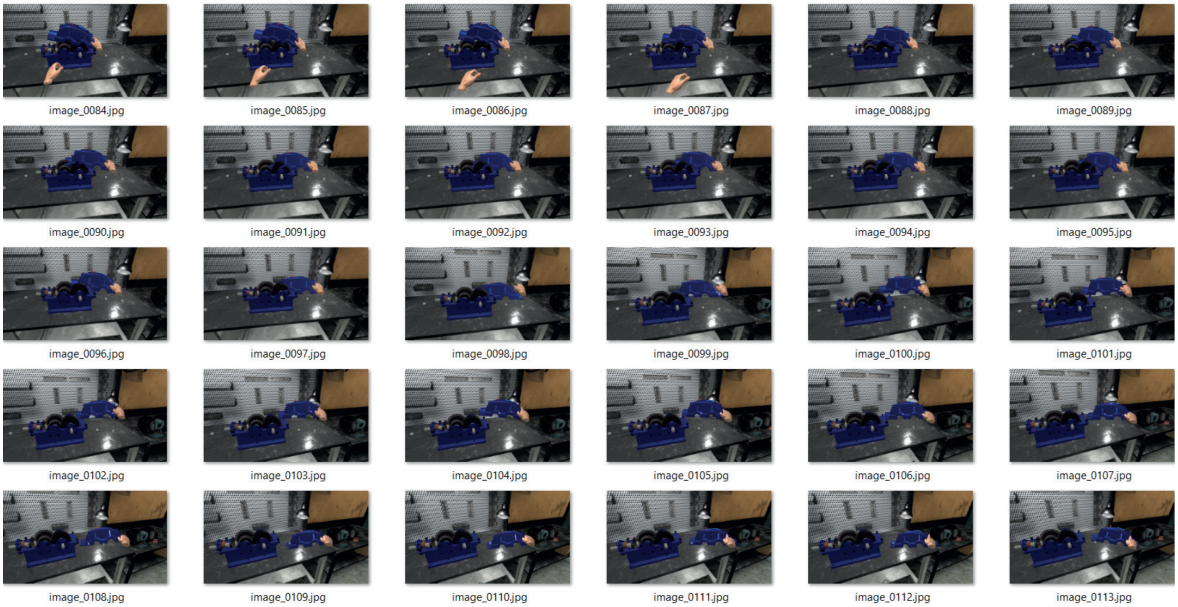


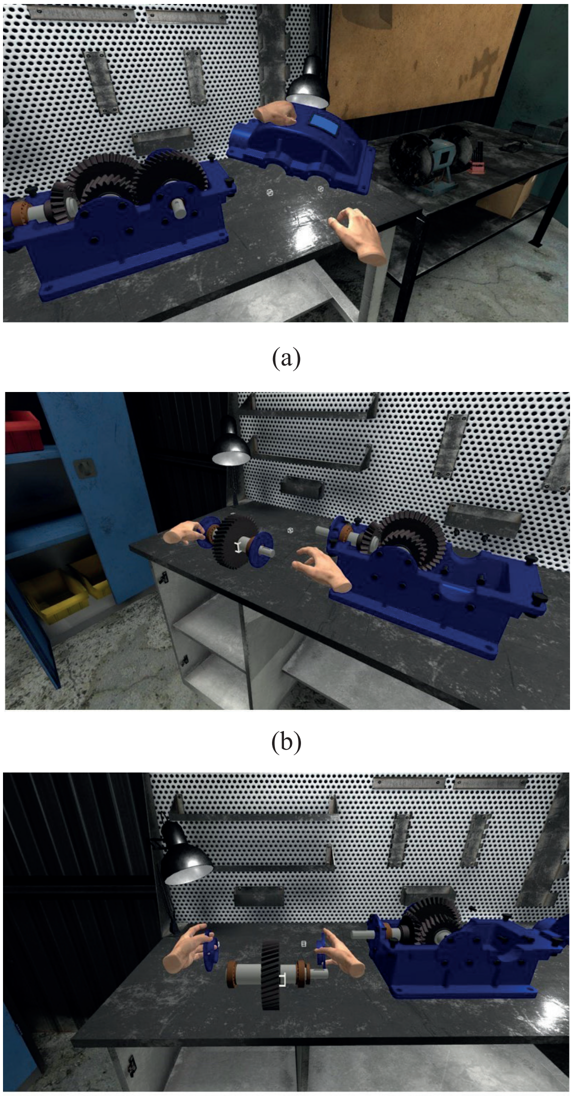
Figure 8: Recording of image sequences in VE.

We used these recorded image sequences in order to evaluate the correctness of the students' performances, as well as to understand the reasons for any mistakes or alternative (however correct) ways of performing the tasks.

From the primary result, we could observe the posture and working process from image sequences of participants' working sequence. The observation from the image sequences revealed that there were 5 participants using their left hands to separate the cover part in step A, instead of their right hands as show in Figure 9(a). Four of them, however, were left handed, while one of them was ambidextrous.

There were two participants trying to work in steps C, D and E at the X position, which is an inappropriate working position as show in Figure 9(b). In addition, there were 3 participants trying to work in step D and E at the same time, instead of having to separate piece by piece as show in Figure 9(c). They would like to challenge the work on process D and E at the same time in order to reduce working time.

We can summarize these results according to our observation and perspective as follows: 1) we should consider the process and placing area of the cover part for left-handed and ambidextrous people. 2) Due to the fact that the working areas at the position X and Y are closely together, some participants felt that it was convenient when they performed their tasks at the same position. 3) In the virtual environment, the participants felt like safe and were therefore inclined



(a)

(b)

(c)

Figure 9: An inappropriateness of participants' hand motion.

to make mistakes. We should to add some warnings to virtual environment to indicate to them that they are about to perform tasks in a manner that is unsafe or simply not correct.

In this research, we also investigated perception levels in the virtual experience, as well as the perception level from using the VR device by participants, including any side effects from using VR device. A summary of the main evaluation results is shown in Table 1. They are divided into three parts: 1) perception level in virtual reality experiencing, 2) perception level from using VR device and 3) side effect from using VR device.

- Perception level in virtual reality experiencing. This part consists of 8 questions. The first result is shown that almost 55.56% of participants strongly enjoyed experiencing the maintenance training through virtual reality technology.

Then, 48.15% of participants said that the virtual reality experience for maintenance training is very interesting. At the number of 51.85% of participants were felt fully-immersive about the virtual reality environment. Almost 59.26% of participants were highly totally focused on virtual environment when they experience on it. Then, the number of 51.85% of participants want to learn more when they experience on the virtual reality technology. The next result is also shown that 48.15% of participant strongly believed that using virtual reality technology has possibilities of enhancing the effectiveness of training. Almost 62.96% of participant strongly believed that virtual reality technology could be useful for training. In addition, 44.44% of participant believed that learning by using the virtual reality technology was easy.

- Perception level from using VR device. In this session 2 questions were about display devices involvement, including the mobility of devices. The result is shown that 55.56% of participants said that the HMD device is highly flexible to interact with, and 48.15% of participants felt that HMD device and the content in this platform is easy to use.

- Side effect from using VR device is studied via the feeling of participants after they trained in the

VR-TMT platform. 3 questions were used to evaluate this filling. The first result is shown that 29.63% of participants not really felt headache during using VR device.

Then, 37.04% of participants not really suffered any physical tiredness when they interacted with VR device and virtual environment. In addition, 29.63% of participants said they not really suffered visual tiredness when they interacted with VR device and virtual environment.

The result is shown that the user experience on the VR-TMT platform has a good level of perception. In addition, the ease of use of the content and devices of the VR-TMT system is quite easy to use as well as

Table 1: Test result (SD: strongly disagree, D: strongly agree, N: neutral, A: agree, SA: strongly) agree)

Question	SD	D	N	A	SA
I enjoyed experiencing the maintenance training through virtual reality technology.			4	8	15
I would say that the virtual reality experience for maintenance training is very interesting.			5	9	13
I felt fully immersive about the virtual reality environment.			5	14	8
When experiencing the virtual reality, my attention was totally focused on it.			3	8	16
Experiencing the virtual reality is made my curiosity and want to learn more.	1		2	14	10
I believe that using virtual reality technology has possibilities of enhancing the effectiveness of training.			2	12	13
I believe that virtual reality technology could be useful for training.			1	9	17
Learning by using the virtual reality technology for maintenance training was easy for me.		1	7	12	7
I found that the HMD device flexible to interact with.			1	15	11
It was easy for me to use the HMD device and the content of this platform.			7	13	7
I felt headache during using VR device.	8	9	5	3	2
I suffered physical tiredness when I interacted with VR device and virtual environment.	10	9	4	2	2
I suffered visual tiredness when I interacted with VR device and virtual environment.	8	6	9	1	3

flexibility to carry. Users can use VR-TMT platform to train anywhere and anytime according to the need. A majority of user's experience very few side effects, both physical tiredness and visual tiredness. But it would be difficult to claim that this result can be applied to all platforms using VR technology. In all areas of maintenance work.

However, the immersive experience can help the users to perceive the working experience in the virtual environment, which is the intent of the research.

According to the limitation of LMC sensor, the new devices would be considered, such as Data Glove or Cyber Glove which can increase the distance to detect the user hands as well as it can increase the level of perception by adding haptic and force feedback. In the next step, we will further develop our concept and platform in order to study the actually required working time and to evaluate the appropriateness of movements from the ergonomic perspective. In addition, we also are developing the VR-TMT platform to be able to classifying hands gestures and creating the Virtual Working Instruction (VWI).

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