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Virtual Training for the Maintenance of Machine Tools

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ABSTRACT

As part of the digital transformation, systems and processes are increasingly being planned, adapted and tested using computers. Virtual reality (VR) offers attractive opportunities for qualifying employees and enables the practical acquisition of knowledge through virtual training. A virtual learning environment enables methodical knowledge and practical skills for the maintenance of machine tools to be conveyed in a vivid way using virtual training. The article describes the development of a virtual learning scenario for virtual training in the maintenance of a lathe. The outlook describes the combination with a multimedia maintenance plan.

Keywords: Virtual reality, Virtual training, Maintenance, Machine tools, Learning scenario, Human machine interaction, Learning success, Multimedia

INTRODUCTION

Demands such as the increasing flexibility of work tasks, the handling of complex products, high follow-up costs in the event of misconduct or dynamic product variations within production, which place physical and mental demands on people, require innovative technical and organizational aids (DIN EN ISO 6385, 2016), (BMAS, 2016). In order to meet these requirements, digital technologies such as virtual reality (VR) open up new potential and approaches for self-directed and self-organized learning processes. In mechanical and plant engineering, efficient maintenance as well as the safe operation and use of machine tools are among the employee qualifications that are critical to success. Maintenance tasks include the inspection, servicing and repair of lathes. Digital technologies provide new potential and approaches for knowledge transfer for learning these tasks (Dörner et al., 2013). For example, there are training simulators for learning how to operate aircrafts, which make it possible to train specific scenarios and the necessary operating maneuvers realistically and without risk, which are difficult to simulate in reality (e.g. landing in windy conditions). With the help of these scenarios, the pilot's behavior can be analyzed, thereby uncovering possible misconduct and eliminating it prospectively (Foerst, 2020). The use of VR technology in civilian pilot training significantly reduces error rates as well as training costs in real operations (Dörner et al., 2013). For machine tools, such as CNC-controlled lathes and their specific operating actions in the area of maintenance processes, such VR-based simulators are currently only available to a very limited extent (Hirt et al., 2019). Here, too, the potential for damage to people, machines or tools in the event of accidents or operating errors in the process can be enormous. In addition, the efficient use of VR technology in the form of virtual training can significantly reduce unproductive machine tool downtimes.These are caused, for example, by unsafe operation, operating errors or training processes on the real machine itself.

The virtual learning scenario for virtual training, which is presented in the article, takes up the approach of VR-based pilot training. It is then transferred to the requirements of machine tool maintenance in order to rule out incorrect behavior or operation on the real machine as far as possible. An exemplary use case on a lathe was analyzed and methodically processed for this purpose.

Basics

Motivation

Current learning applications such as blended learning support, among other things, basic employee qualification or the development and expansion of knowledge. "Blended learning is an integrated learning application in which networking via the internet is used in conjunction with "traditional" learning methods and media" (Goldhahn, Eckardt, 2021). In contrast to VR-based technologies, the main disadvantage of blended learning is that practical knowledge and skills can generally only be taught using real objects.The added value of VR-based technologies, as the basis of virtual training, lies in the temporal and spatial flexibility of the learning processes (Goldhahn et al., 2019), but also in the sustainability of what is learned as a result of virtual "doing". Depending on the VR system used (hardware) and the VR application developed (software), VR enables a fundamentally realistic representation of specific work environments and the work tasks that occur in them, which makes it possible to practice on realistic objects (Goldhahn et al., 2019). A virtual learning environment, which virtualizes a real work area and forms the basis for virtual training, uses integrated, didactically prepared content to clearly convey methodical knowledge and practical skills to increase operating safety on production systems. The focus is on typical operating actions such as the deliberate, sequential actuation or disassembly of attachments on machine tools. In order to ensure the desired learning success (error-free, safe execution of the real work task) and employee acceptance, the correct structure of the operating sequences and an exact representation of the graphic interfaces are conducive to learning and acceptance.

Virtual Reality (VR) and Virtual Operations

The literature defines VR as the "visual presentation and manipulation of 3D data in real time" (Hirt et al., 2019). According to (Goldhahn, 2003), VR is characterized by three properties:

- Immersion (realistic presentation and perception)
- Interaction (influence and change in real time)
- Imagination (experience as a quasi-real world).

VR appeals to people's visual, acoustic and/or haptic senses. The visualization and perspective changes ensure a realistic perception. Publications such as (Goldhahn, Eckardt, 2021) underline that the VR systems available on the market (e.g. Head Mounted Display (HMD)) differ in the degree of separation of the user from the real world and the integration into a virtual environment. An HMD, such as the HTC Vive pro, with a high degree of immersion (Engel, 2019) enables free interaction with both hands using controllers at a virtual workplace, allowing work tasks including operating actions to be trained in a targeted and repeated manner. A VR-based operating action refers to a holistic virtual operating process for initiating, executing and completing a function on a virtual technical device, which can have an immediate effect on the virtual technical device, even in several stages, and thus supports virtual training.

Virtual Training

In virtual training, as many action situations as possible are provided in the sense of problem-solving or action strategies (Hirschle, 2020). In the context of using VR for virtual training (also known as "learning-related interactivity"), the literature speaks of a high level of practical relevance and "good results in terms of learning effectiveness" (Hirt et al., 2019) (Wannemacher et al., 2020).

Virtual training supports the teaching of procedural and action-related skills and at the same time provides walk-in realistic environments (training worlds) that serve as orientation in real space and increase learning motivation and acceptance (Schwan, 2006). The virtual learning scenarios are based on the operating states of the machine tools (e.g. normal operation, start-up and shutdown (shift-related), commissioning and decommissioning) and activities required for part-specific machining such as set-up, insertion, operational activities, etc. (VDI, 2012) (VDI 3699) (Zühlke, 2012). Work tasks such as the commissioning of a machine can be mapped in a virtual learning scenario and subsequently trained within a virtual learning environment (Hirt et al., 2019) (Goldhahn et al., 2019). This reduces the number and severity of errors that occur during real commissioning and can endanger people and a real machine. In preliminary work, three types of virtual learning scenarios were defined and developed in relation to the commissioning of a milling machine with different learning requirements for training with an HTC Vive pro. The employee training was then carried out on the hardware side with the VR glasses HTC Vive pro and on the software side with an in-house development of the Mittweida University of Applied Sciences (see Figure 1).

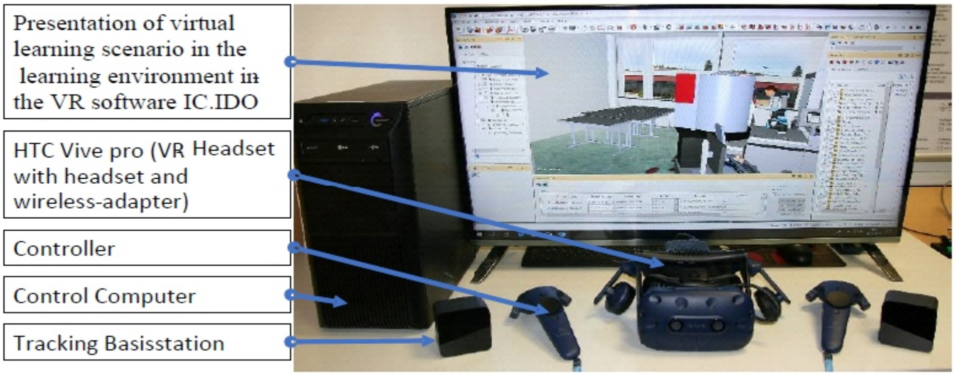

Figure 1: Components of the VR-system as base of the virtual environment scenario (Goldhahn et al., 2021).

Development of the Virtual Learning Scenario

Describe the procedure for developing a virtual learning scenario (Goldhahn, Eckardt, 2021). Based on dynamic 3D models, it allows virtual training courses to be developed in order to qualify users in the operation and execution of activities on machine tools. The real test environment for which virtual training courses are developed was modeled on the data side using the CAD software SolidWorks and transferred to the VR software.

In order to be able to define the qualification required for the virtual learning scenarios, the approach according to (Eckardt et al., 2020) is expedient. This approach uses a level model that provides adequate learning content for different levels of the required and existing skills of the respective employee (see Figure 2).

According to (Eckardt et al., 2020), the operating complexity (BK) and the operating level (BL) contained in the level model were defined in three stages. This is necessary in order to structure and classify the complexity of virtual training.

The operating level determines the amount of information conveyed for the successful implementation of the learning scenario that is entered by the user. Furthermore, the operating complexity includes the degrees of freedom and dependencies in the learning environment available for the respective virtual training.

OL = operator level Improve the level of information provided for the specific operator action	level	3	OC	1	OC	2	OC	3
			OL	3	OL	3	OL	3
		2	OC	1	OC	2	OC	3
			OL	2	OL	2	OL	2
		1	OC	1	OC	2	OC	3
			OL	1	OL	1	OL	1
			1		2		3	
			OC= operator complexity Improve the level of control and the number of decisions made by the user					

Figure 2: Step-by-step model of VR-based operating actions for classifying learning scenarios (Goldhahn, Eckardt, 2021).

Based on this approach and the step-by-step model developed, a virtual training course on the maintenance of a lathe and its required operating actions was developed.

The virtual learning scenario includes information-based (visual, auditory and haptic support) guided operating actions. In this training, the user navigates themselves through the learning environment and works through the respective operating actions virtually in the predefined sequence. Errors in the sequence of operations are not possible, which basically ensures the successful completion of the training (operator level 2, operator complexity 2). Figure 3 below visualizes the lathe in the new virtual learning environment using the example of maintenance.

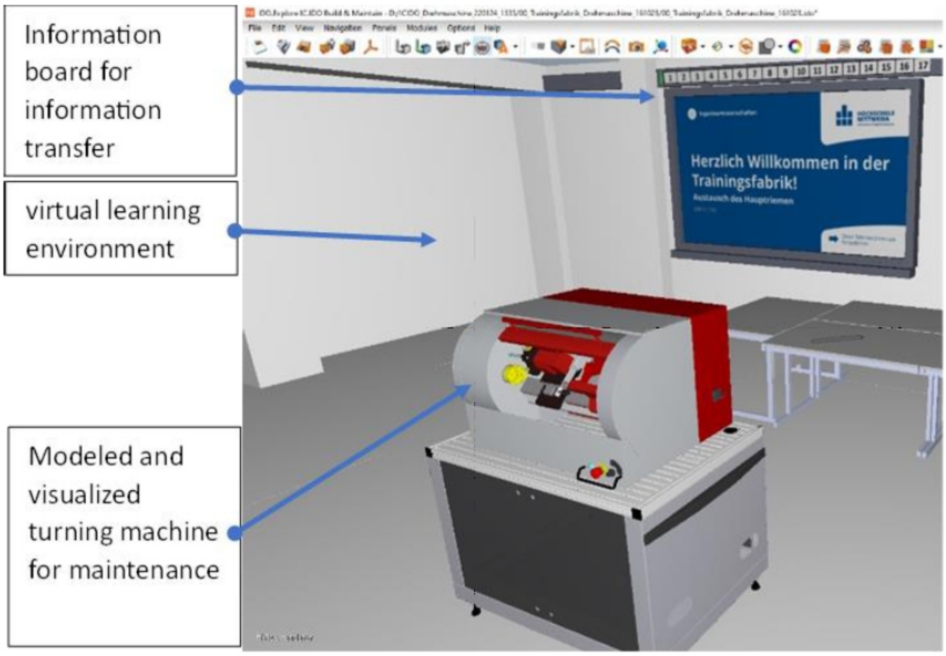

Figure 3: Virtual training using the example of the maintenance of a turning machine.

First Findings From Tests

Figure 4 shows a test person carrying out the virtual training. In the figure, she has the task of changing the belt of the main drive of the lathe (marked in yellow in the screenshot of the virtual scene outlined in red). To do this, she is provided with sequential information via the information panel, which contains the operating action to be performed (What is to be done? Why? How?). The locations of the respective actions are shown by markings, e.g. boxes around screws. In the case of complicated procedures, animations illustrate the sequence of actions. A progress bar above the information board provides positive feedback for positive virtual execution. The board then displays the next process.

Initial trials with four test subjects have already identified the advantages and disadvantages of virtual training.

Advantages

- System-based, process-oriented guidance of learners through information boards
- User can familiarize themselves with the learning environment without time pressure
- Less effort required to explain the operating action to be performed in the real environment
- Little effort required to explain the spatial position of the next operating action
- Virtual animations can be easily integrated as video sequences on a multimedia interface (PC or tablet).

Figure 4: Virtual training using the example maintenance of a turning machine.

Disadvantages

- Relatively high effort required to create, test and technically stabilize the virtual learning scenario
- Special maintenance tasks and background information can be better described in multimedia and text form
- Learning from mistakes in the event of an incorrect sequence of actions is not part of the virtual training.

Outlook: Supplementing Virtual Training With a Multimedia Maintenance Plan and a VR Exercise Scenario

As a consequence of the advantages and disadvantages of creating and using the purely virtual learning scenario, a multimedia maintenance plan is currently being developed. This plan is structured hierarchically and sequentially in accordance with human action regulation. Data, photos, CAD representations and video sequences from VR animations supplement and illustrate the necessary maintenance steps using the example of replacing the drive belt on a lathe. This belt is a flexible component. Its mechanical pre-tension is determined by force measurement and deflection. As this process can hardly be depicted virtually, a purely multimedia description is a particularly suitable case here.

Previous tests have shown that untrained people should run through a standardized training scenario on the head-mounted display (HMD) with its controllers. This has already been created using the example of the system commissioning of the Training Factory 4.0 at Mittweida University of Applied Sciences (Goldhahn et al., 2021). It is necessary to check whether this scenario can be used across all subjects.

The virtual training in the VR environment is then followed by a practical exercise or the performance of maintenance on the real machine. This creates a holistic approach for a combination of multimedia maintenance plans with virtual training and real training of manual skills (Fig. 5).

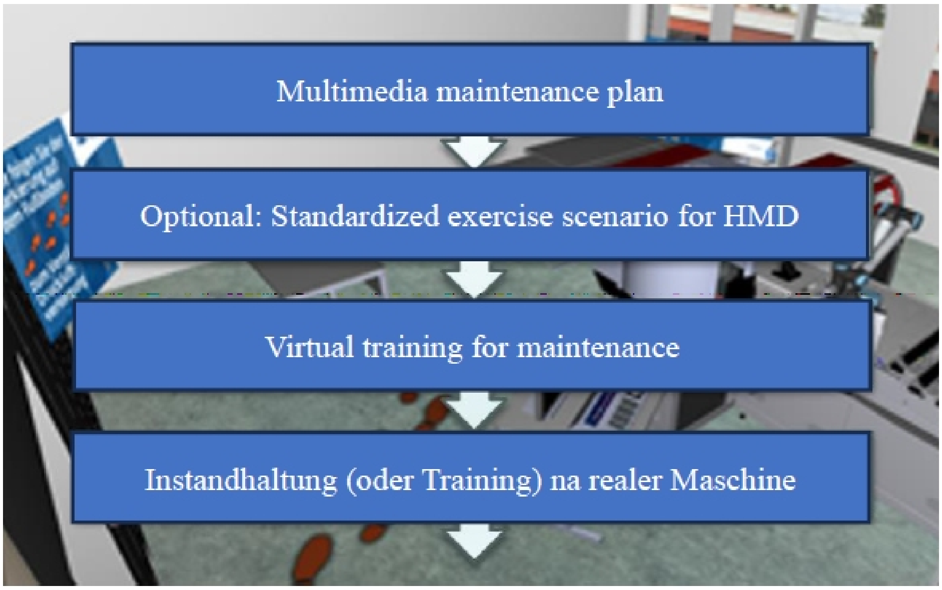

Figure 5: Holistic approach to virtual training for the maintenance of machine tools.

In addition, the development of virtual training with components for the autonomous execution of maintenance operations is conceivable, whereby errors can also be made by the operator and lead to corresponding error information from the learning environment (operator level 3, operator compexity 3).

CONCLUSION

The current state of development of virtual training covers the steps required to maintain a lathe. Virtual training is effective when using suitable VR technology and for learning essential operating actions on machine tools. Virtual training offers advantages such as:

- Recognize your own mistakes and consciously avoid them
- Virtual "practical" trial and error instead of abstract frontal teaching
- Consideration of different levels of knowledge among employees.

The practical need for the development and application of virtual learning scenarios arises primarily from the targeted reduction of operating errors by employees, which avoids hazards to the machine/system or tools, but also to the employees themselves. Unproductive downtimes can also be reduced.

The existing state of development of virtual training must be supplemented in future by further tests in combination with a guided interview. The interview specifies the needs-oriented learning content and, if necessary, the training requirements with regard to the basic VR application.

The holistic expansion of purely virtual training to include learning by means of a multimedia maintenance plan and practising manual activities on the real machine enables specific qualification in terms of knowledge, skills and abilities for the respective task. A virtual training scenario helps newcomers to the world of VR goggle technology and its controllers.

This creates a suitable method-based tool that is intended to improve learning success and thus qualification and produce a robust learning outcome.

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