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Evaluation Framework for Virtual Training within Mixed-Model Manual Assembly

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Abstract: The low volume-high variety strategy of the companies increases the need for well-trained operators. The operators have a much larger cognitive load than before and their expertise must be kept up to date at any time. To solve this problem, efficient training programs must be maintained. A physical replica of the real setting to perform an assembly training is often a too large investment. Therefore, a virtual replica is introduced in many cases. This paper gives an overview of reported experiments on virtual training for manual assembly. All experiments are classified based on some key elements: the evaluation method, the interaction interface and product complexity. An evaluation framework is proposed to compare different virtual training systems. This benchmark will be used in future research to determine the industrial usability of virtual training approaches for manual assembly in mixed-model environments.

Keywords: Virtual Training; Mixed-model Assembly; Operator; Virtual Reality; Benchmark

1. INTRODUCTION

In order to be competitive, manufacturing companies must be able to assemble many kinds of products at the same time on an assembly line (Dertouzos et al. (1970)). The concept of mixed-model assembly is about creating one main product, but during the assembly process, different options can be added to the model. Within the automotive industry, mixed-model assembly is already integrated for decades (Fisher and Ittner (1999)). The use of a mixed-model assembly line generates a more difficult and varying job for the operators (Hu et al. (2008)). ElMaraghy et al. (2009) declare that 15 - 70% of the overall manufacturing time is absorbed by the assembly process. Furthermore, approximately 40% of the cost to manufacture a product is taken by the assembly process (Ritchie et al. (1999)).

Automated assembly is supposed to be much faster and more accurate than manual assembly. However manual assembly is more flexible to changes in the production process. Especially when the product life cycle of the created products is rather low, it is beneficial to make use of manual assembly (Yoshimura et al. (2006)). The importance of a well trained operator is considerable. The training program can be crucial for a manufacturing process to be profitable even at an early stage of the production of a new product.

Next to skilled operators, the ramp-up time of the manufacturing process is an important factor to be competitive within the consumer market. To shorten the ramp-up time, Virtual Commissioning (VC) is an effective tool. The objective of VC is to avoid errors by running the process in a virtual replica of the real setting. In current assembly engineering projects VC is principally used to debug control software and to optimize the material flow within the process (Klingebiel et al. (2010)).

A possible next step to improve the response of a manufacturing process on the changing market demand is to base the training program for an assembly operator on a VC tool. In other words integrating the operator in the virtual environment to train the assembly tasks during VC. The opportunities of virtual training are already acknowledged for years, consequently a lot of research has been done in the field. The most known examples are the aerospace (Loftin (1994)) and chemical industry (Guisinger and Ghorashi (2004)). The most significant advantages of virtual training in these sectors are reducing costs as well as reducing dangerous circumstances. Virtual Reality (VR) is not new to product assembly lines either. VR can be used to do line balancing in an efficient way (McMullen and Frazier (1999)). Further, ergonomics of an operator while assembling are often checked via a VR tool (Reuding and Meil (2004)).

Bringing the operator into the VC, will shorten the production ramp-up by training the operator already before the real start-up of the manufacturing process. Moreover, a virtual training system can be used at any time. An offline training method implies no need for the real setting since it is replaced by a virtual replica. Subsequently the cost of an experimental set-up for training or the downtime of a production line can be avoided. In that case, virtual training provides an efficient solution when virtual models of the workspace, tools and parts are available. The change to a training program for a new product could require little additional effort, so different scenarios can be trained in a short term.

When considering the industrial relevance of a training

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system, two elements show up: investment and training efficiency. An important aspect is the used hardware as it affects both elements (in)directly since a better interface can make the learning transfer more efficient. A better interface trough more realistic presentation and more natural motion captures will result highly probable into a larger cost of the resulting system. In section 2 an overview of the previous research by experiments on virtual training for manual assembly is given. All experiments are classified based on some key elements: the evaluation method, the interaction interface and product complexity. Based on these elements, a benchmark for experiments concerning virtual training for manual assembly is composed and presented in section 3. As future research will focus on mixed-model assembly, the influence of product variety on assembly is shown. Conclusions and directions for further research can be found in section 4.

2. LITERATURE REVIEW ON VIRTUAL TRAINING EXPERIMENTS FOR MANUAL ASSEMBLY

In literature, a lot can be found on virtual training, nevertheless the application of manual assembly is not studied on a large scale. A review of the experiments regarding virtual training for manual assembly was made in order to get an impression of the typical work methods and experimental set-ups.

2.1 Evaluation methods

Objective evaluation The experiments make use of a comparison of two or more groups, where one group counts as a reference group that is subjected to a conventional training and one or more groups that are following a virtual training program. The conventional training does change from experiment to experiment. Boud et al. (1999) use a simple 2D drawing to indicate how the product should be assembled. This is a basic form of conventional training and can only be applied when the product complexity is not high. Another method of providing a conventional training is to demonstrate a video where the product is composed (Adams et al. (2001);Vélaz et al. (2014)). The last technique to train the reference group is a real training. This might be an expert-based training (Malmsköld et al. (2007)) or an acquaintance with the real components and the assembly tasks (Peniche et al. (2011)) or a simplification of the real components (Oren et al. (2012);Carlson et al. (2015)), where the sequence of the assembly tasks is taught. The training strategy for the reference group affects the results and conclusions of the experiment. The lack of homogenous choice of this particular group makes the comparison of different test results very hard and subjective.
After pursuing the training period, an evaluation is made by the assembly of the real product. There are different methods to evaluate the effectiveness of the learning transfer. In many cases, the assembly time of the real product is registered for both reference group and all test groups. Based on the average total times, the conclusion is formulated. Despite a difference that can be noticed in a lot of experiments, there is not always a statistically significant prove of the indicated difference. When experiments are done with groups of 5 subjects, the statistical analysis did never indicate a significant effect.
Since virtual training does not make use of the real components, the first assembly time can be influenced by the fact that the operator needs to adapt on the new type of components. The solution to get rid of this effect is registering the assembly time of the next 'x' products and getting information on the learning curve (Wright (1936)) in both cases. Based on the learning curve, the learning coefficient can be found. The learning coefficient is the rate of learning by doing. Peniche et al. (2011) did subject the trainees to the assembly of a milling machine seven times after finishing the virtual or conventional training, but no difference between the two groups was found. The opposite effect can also be measured, forgetting by not performing a task during a certain period, and can be visually represented by the forgetting curve. Carlson et al. (2015) did research on this last named effect and set up an experiment where an initial test right after the training period and a retain test were compared based on the assembly times. The aim of this experiment was to evaluate if the training strategy influences the forgetting curve of several training methods where there was a mix of virtual and real training, and a test with colored parts and non-colored parts.
All methods of evaluation above are based on the quantitative measurement of the real assembly tasks, where the assembly time should be as short as possible. As in a manufacturing company the quality is as important as the production rate, errors can likewise indicate the effectiveness of the training strategy. Malmsköld et al. (2007) analyzed the error rate of the real assembly tasks and determined that there was only a significant difference between the error rate of both groups during the first batch. The errors were separated into "'what to perform"'and "'how to perform"' errors. The "'what to perform"' errors consist out of a range of errors where the operator needs assistance because he forgot what task he must perform next or what parts he is expected to assemble. This is linked to the knowledge of the operator. On the other hand the "'how to perform"' errors are moments where the operator is not able to perform the task due to a lack of skills or because the operator is not familiar with the tool. This type of errors can be named as the motor skills and finesse of the operator. Making a differentiation of errors can give more insight on the type of learning transfer via the training system. A more specific qualification of the error types was made by Vélaz et al. (2014). Three types of errors were distinguished: forgetting a step, wrong placement and wrong attachment, where wrong placement signifies i.e. a wrong orientation of a component and wrong attachment refers to a wrong manner of attaching. When assuming the categories of knowledge and motor skills, forgetting a step and wrong placement is categorized into the knowledge section and wrong attachment represents the deficiency of motor skills.

Subjective evaluation Another aspect of virtual training systems is the usability. The usability is not a quantitative measurement, rather an individual experience. Getting a general idea of the operator's impressions on the system can be done by a subjective evaluation. Xia et al. (2012) evaluated a haptic-based virtual environment system for assembly training of complex products by a questionnaire to get a view on the findings of the users. They divided