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Dual Reality for Production Verification Workshops: A Comprehensive Set of Virtual Methods

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Abstract

In automotive industry, planning of manual assembly is getting ever-increasing complex, diverse and variant-rich due to ever-increasing market demands for more models and derivatives with shorter life-cycles. In order to reduce the costs for building physical prototypes before ramp-up processes, we present a comprehensive set of virtual and augmented reality methods for real-time assessments of manual assembly tasks used in interdisciplinary production planning workshops. This novel mixed reality assessment system unifies innovative interaction concepts with display technologies from a variety of domains. True-to-scale floor projections, interactive tangible tabletops, powerwalls and head mounted displays are used in combination with markerless full body motion capture and motion controller interfaces. Therewith, production planners in workshop situations are enabled to collaboratively plan and optimize station layouts, author 3D scenes and assess product and process related topics, such as buildability, reachability, assembly and disassembly routines. An in-depth evaluation on collaborative task performance using differing visualization scenarios is presented and discussed.

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Keywords: virtual production planning; manual final assembly; cyberphysical equivalence; visualization methods; markerless full-body tracking;

1. Introduction

Automotive industry is currently facing changed market requirements. Due to ever-increasing market demands for a bigger variety of models, derivatives and customization options, production planning is getting gradually more complex, since these changes need to come along with more planning and verification effort.

Since early physical prototype cars are highly cost intensive, there is an effort to build less of them during product development process. Additionally not all combination possibilities of derivatives and extra equipment can be physically assessed. Therefor digitalization is one promising approach to overcome these additional efforts [1]. Digital methods for assessment of product and production verification are already well-established in industry, so-called methods of the digital factory [2]. Digital verification methods are able to improve process models as well as product quality. Simultaneously, higher confidence in planning quality and less errors during ramp-ups are achieved in earlier stages [3].

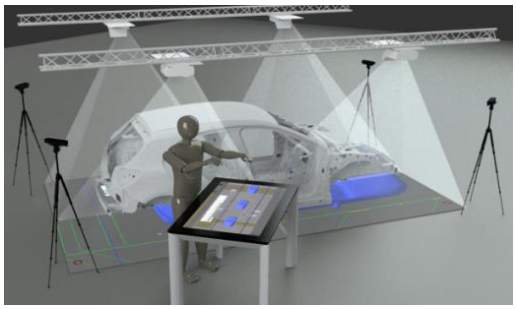

Figure 1: Holistic set of virtual methods integrated to a mixed reality assessment system for production verification workshops

Even when building less physical prototypes, verification tasks have to be performed in the same time-frame and level

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of quality. Filling this gap, physical mock-ups (PMUs) [4], digital mock-ups (DMUs) and mixed mock-ups (MMUs) [5] are used in product engineering to improve product quality and speed up development processes. For production engineering, digital and mixed mock-ups are not deployed for extensive use yet, since virtual technologies still are still in research state or complex expert systems. Additionally the preparation of virtual and mixed assessments scenarios are highly time-consuming.

In contrast to the state of the art, we propose a set of virtual methods (see Figure 1), in order to enable immersive, collaborative and intuitive workshop situations, since these interaction and visualization techniques positively influence task solving performance and quality [6]. Direct interaction using virtual and real models simultaneously, is one of the core concepts for interface components (compare [7]).

The remainder of the paper is structured as follows: It starts with a introduction on state of the art and related work in the context of virtual production planning research. Then an overview on typical tasks in production verification workshops and their organization is given. Based on these insights, a mixed reality assessment system is presented. Subsequently, three exemplary applications using different combinations of technologies are introduced. Then, an evaluation on task performance and error rate within workshop situations using different visualization techniques is presented. The paper concludes with an overall assessment of findings and outlook on further optimizations options.

2. Virtual methods for production planning

In the past decades, various publications have been released in the domain of virtual environments (mostly virtual reality) and interaction design for industry purposes. Two different clusters of publications can be recognized: Conceptual publications on methods and technologies and specific application related publications.

Conceptual publications: In 2010 Seth et al. presented a profound literature review on research in virtual reality for assembly methods [8]. Winkes [9] presented in 2015 a general method on how to use virtual reality for assembly planning and proposed a procedure on how to avoid possible planning failures. Zachmann presented in his doctoral thesis [10] a holistic framework, algorithms and techniques for virtual reality in assembly simulation. The three main contributions are efficient interaction metaphors, an easy to use authoring tool and physics-based simulation with collision detection algorithms.

Application related publications: Besides theses conceptual and technical advances in research, many specific application related virtual assessment publications have been presented. Already in 1999 Gomes de Sá investigated the steps needed to applicate virtual reality (VR) in the assembly and maintenance process of automotive industry and discussed how to integrate it into business processes [11]. Aurich et al. presented results on virtual reality-based continuous improvement workshops (CIP) for an agricultural machinery manufacturer [12]. CIP workshops are also carried out by production planners but in contrast to production preparation, they focused on critical work stations for their iterative optimization workflows. A large part of the previous work is related to factory and assembly station layout planning [13–15]. In this context, Pentenrieder et al. presented an augmented reality (AR) based application to overlay a shop floor with a virtual model of an assembly line [16].

Besides these academic approaches, there is a wide variety of commercially available virtual reality products for industrial planning, simulation and verification. For example, imk automotive, Dassault Systems, Siemens, ESI, etc. offer software bundles for virtual assembly simulation tasks, like virtual training, station layout design, process and factory planning, knowledge capture or ergonomic evaluations.

Yet, none of the above mentioned systems cover multiple assessment use cases, none offer a mixture of efficient interaction metaphors, none are optimized for collaborative workshop situations, and none offer a seamless integration of PMUs at the same time.

3. Verification workshops for final assembly planning in the virtual continuum

Production planning workshops aim at improving planning quality for multiple disciplines in order to guarantee an efficient and smooth ramp-up of producing products. Since the domain of production planning is cross-functional and interdisciplinary, these moderated workshops bring together managers, planners, product engineers, ergonomics experts, time-measurement specialists as well as assembly operators. All of these stakeholders directly profit from the domain specific knowledge and hands-on experience from each participant.

In purely hardware-based workshop situations, all assembly parts and resources have to be physically present. Assessment tasks are solved by assembling the PMUs. In practice, it depends on the current state of the product development cycle if digital or hardware-based production verification workshops are being held. Overall, the number of traditional PMU-based scenarios is decreasing. However, both for hardware and virtual assessments, typical assessment tasks remain the same:

- Reachability
- Collision free assembly and disassembly paths
- Ergonomic evaluations
- Logistics
- Station layout and walking paths
- Work task description verification
- Time verification of assembly process
- Operating resources and handling equipment verification

Depending also on the product development cycle and the remaining planning vagueness (see [17]), the duration and verification tasks differ vastly. For example, for a new product, multiple verification workshops take place for a couple of weeks, for derivatives only delta-contents are being validated in a couple of hours.

Currently, virtual production verification workshops are carried out either purely with the help of hardware-based