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Concept of a Mixed-Reality Learning Environment for Collaborative Robotics

Torsten Sebastian Sievers[a,*], Bianca Schmitt[b], Patrick Rückert[a], Maren Petersen[b], Kirsten Tracht[a]

[a]University of Bremen, Bremen Institute of Mechanical Engineering (bime), Badgasteiner Str. 1, 28359 Bremen, Germany
[b]University of Bremen, Institute Technology and Education (ITB), Am Fallturm 1, 28359 Bremen, Germany

Abstract

In the course of increasing automation and individualization of products, so-called collaborative robots (Cobots) play an increasingly important role. The systematic automation of manual assembly by adding automation components enables efficiency and cost advantages to be realized without the loss of flexibility. Previous industrial robots are not profitable from an economic point of view, due to the high acquisition costs, small batch sizes, and a high number of product variants. In contrast, collaborative robots can be used more flexibly. They offer the possibility of automating work processes and steps to a greater economy. Employees must be prepared for this change within the framework of training and further education, to develop the necessary skills. This article presents a concept for a mixed-reality learning environment that tackles the challenges identified regarding to HRC. Therefore, existing technologies are examined and evaluated for a usage in context of HRC training.

Keywords: Learning Factory; Robot; Human Aspect

* Corresponding author. Tel.: +49-421-218-64833; fax: +49-421-218-98-64833.
E-mail address: Sievers@bime.de

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1. Introduction

Due to the increased production in small series, flexible assembly lines become more important [1]. Especially the assembly is influenced by fluctuations in demand, caused by its proximity to the market as the final production step [2]. Therefore, manual assembly operations with skilled workers using universally applicable tools are usually more economical than automation. Classic automation solutions result in high investment risk in combination with high acquisition costs. To enable a cost efficient production of customer-specifically configured products, flexible automation is needed. In this context, human-robot collaboration (HRC) are discussed as a key technology. [3] As a consequence, the future assembly processes will be defined through the cooperation between human and machine. While HRC promises a high overall productivity and better product quality, the safety of the employees showed a difficult problem [4]. The planning of collaborative assembly tasks can be supported and validated in a simulation using a virtual environment (see Fig. 1) [5]. The simulation is based on the digital twin, enriched with the data from the new product variant and the resource configuration. Together with the virtual environment, the simulation allows an experimental testing of the collaborative assembly process including the human. In order to increase the potential and ensure the safe use of collaborative robots, trained employees are required. [6] Therefore, employees at all levels, from simple skilled staff to management level, must be qualified [7].

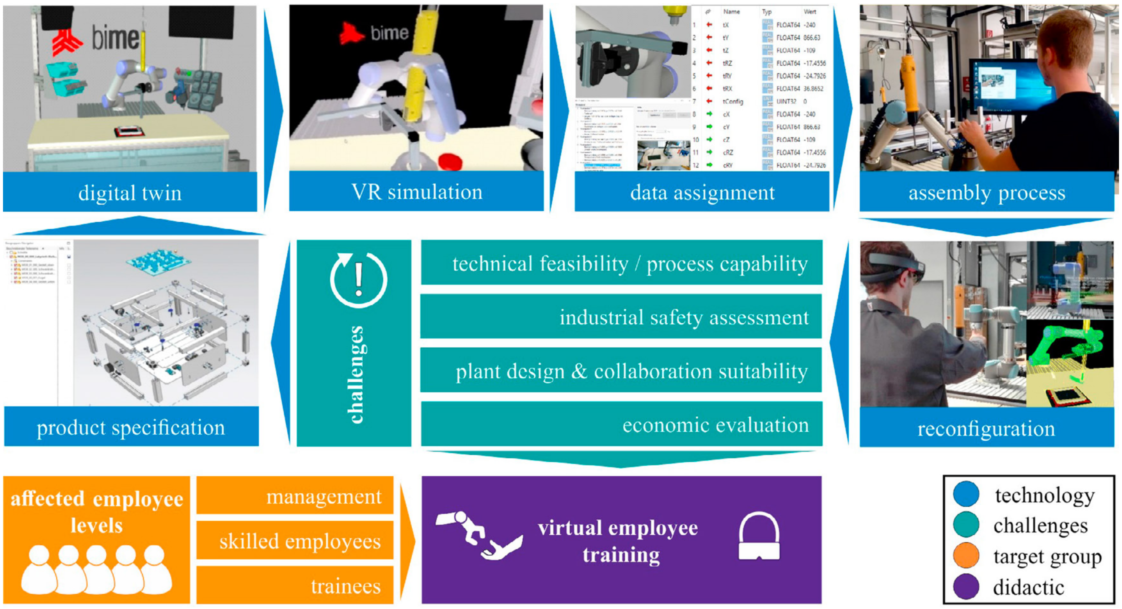

Fig. 1. Required employee training out of product lifecycle robot programming (technological cycle already published in [8]).

Within the companies, the system integrator of the specific collaborative robot will train employees. These training courses are usually limited to product specific basic qualifications and programming knowledge. In research, Tvenge et al. presents a Festo Didactic learning factory focusing on the concept of a digital twin. They visualize the digital twin of the learning factory by using virtual and augmented reality and create learning scenarios for human-machine interaction. [9] Another learning factory for industry 4.0, is provided by the TU Wien. The learning factory contains a HRC assembly station, in which they combine the learning factory approach with a scenario-based learning to prepare the students for future challenges. [10] Oyekan et al. presented a virtual environment where humans can collaborate with industrial robots. The system tracks the human movement and allows an observation on unexpected robot movements. [11] However, most approaches in the context of industrial learning factories are focused more on research and higher education [12]. The initial and continuing vocational education and training for industrial employees is not investigated. In contrast, Filipenko et al. report from a research project in the sector of lightweight-construction, in which a virtual learning environment is used for initial and continuing vocational education and training [13]. The focus is put on specialized production machines, which contain a human-machine interaction. Yet, the term of HRC is not considered.

2. HRC Learning Environment

To qualify employees for collaborative tasks, in which robots are used, the University of Bremen started a research project named KoRA. Initially, the project focus is on qualifying trainees, but also considers further training of other employee levels up to the management (see Fig. 1). A virtual learning environment enables employees to view complex assembly systems holistically, in order to recognize the potential of human-machine interaction and use it in a targeted manner. Numerous companies and schools are involved in the project to ensure practice-oriented development. The teaching and learning concept of KoRA is didactically and methodically based on a learning software that enables a concept for project-based, action-oriented, professional learning with a learning software using Virtual Reality (VR) and Augmented Virtuality (AV).

2.1. The Mixed Reality Environment

The term "Mixed Reality" (MR) is introduced by Milgram and Kishino. At one end of the virtual continuum is the real world, at the other is the completely virtual computer-generated environment "Virtual Reality" (VR). A reality that is supplemented by computer support is called "Augmented Reality" (AR)". Virtual reality, that is supplemented by real elements, such as video recordings, is known as "Augmented Virtuality" (AV). There is a large grey area between the two terms. Therefore, MR, as a more general term, summarizes all applications, in which elements from reality, as well as from the virtual world occur. [14] MR has experienced new growth in recent years. The main driving force for new technologies in this field is the entertainment industry [15]. MR is also often used in medicine for diagnostics, treatment, and training [16]. Head-mounted displays are used as hardware for visualizing the virtual environment, as these have a high immersion effect and are already available as tried and tested standard products for the consumer market.

In the context of HRC, the MR environment allows safe and adaptable testing of new technologies. By safely handling collaborative robots, fears can be reduced and potentials can be demonstrated. To realize all potentials a simple redesign of the entire production process is necessary [17]. Because of that, the existing digital image of a flexible learning factory of the Bremen Institute of Mechanical Engineering (bime) is implemented in a simulation software. Scenarios for the learn and work assignments will be created and integrated into the KoRA MR learning software. They offer different level of difficulty that can be chosen. These differ mainly in the level of detail of the information provided. In a scenario for troubleshooting, e. g. possible sources of error and hints on how to solve them are given for unskilled employees. The learner himself can make the choice of the level of difficulty. The level for skilled employees e. g. is designed for employees who already have several years of work experience. For the vocational training sector, the scenarios are divided also into occupational groups. The subdivision is based on the competencies required in the specific curriculum.

2.2. The Experimental Modular Assembly Plant (EMMA)

The experimental modular assembly plant EMMA (Fig. 2) is a decentralized learning factory consisting of reconfigurable autonomous sub-modules, thus mapping the requirements of versatile production. Different levels of automation are represented, ranging from purely manual to fully automated assembly stations. The aim of this system is to analyze and optimize interaction of different assembly technologies and to implement a human-robot collaboration into a synchronized flow production. For this purpose, two assembly modules are equipped with industrial robots from different manufacturers to represent different controllers. Four modules are designed for manual assembly processes and equipped with electric and manual assembly tools. The manual modules can be supported by additional modules with collaborative robot, depending on the current task. A system for the support of the employees is used, which automatically controls the work progress and gives feedback on the current assembly steps, including an intuitive reprogramming of the robot. All modules are connected with a belt conveyor for product transport and designed from standard industrial components to create a practical assembly environment. Therefore, the EMMA offers optimal conditions for an examination, as it is already available as a digital image and integrated into an MR environment. Due to the physical presence of the system, it is also possible to compare the virtual learning environment with a training session on the physical system.

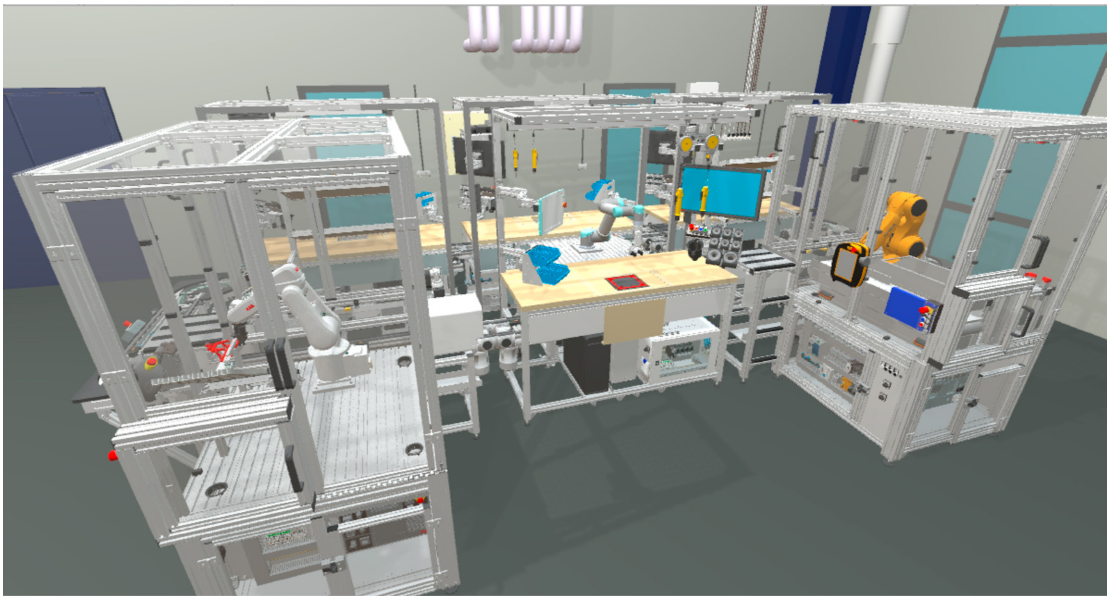

Fig. 2. Digital image of the Experimental Modular Assembly Plant (EMMA).

At the experimental production line, a marble maze is assembled, that is designed to be able to easily disassemble. The production process requires various joining processes, from clips, to screws, to the knotting of a rope. Furthermore, there is the possibility to assemble different variants, which results in variable assembly scenarios.

3. Didactical Concept

In the teaching and learning concept of KoRA, the approach of learning and work assignments according to Howe and Knutzen [18] is integrated into a MR learning software. The MR learning software tackles the challenges that exist in cooperation with collaborative robots and supports employees and trainees in coping with them. The first challenge (see Fig. 1) is to assess the potential of robot technologies. The virtual environment in combination with the modular assembly system offers the possibility for various optimization scenarios. The developments of collaborative robots, which enable a direct cooperation within a working space [3], are especially important. Employees tend to associate robots with "rationalization" and "job losses", which is an obstacle to dealing with robot systems [19]. It is therefore important that employees understand the potential of (new) robot technologies [20]. The understanding conveyed in the learning environment therefore serves to reduce unfounded fears.

The second challenge arises in the field of (occupational) safety. Classic industrial robots were only allowed to operate within corresponding safety fences, but collaborative robots are only partially or not at all required to have intervention and access protection devices. For this reason, it is particularly important to consider this change, in order to avoid hazards. The virtual environment allows therefore a safe experience of the new working environment. The development of problem solutions is defined as the third challenge for employees. In view of the increasing flexibility of production, employees are increasingly required to solve problems independently within the flexible production processes and to make necessary decisions [21]. The MR environment can provide support in problem-solving and decision-making. The simulation of realistic, flexible, robotic-supported action situations in the MR environment enables the virtual transformation of the process in order to develop, try out, and optimize (creative) approaches to solving problems. A fourth challenge is the way in which human and machine communicate and cooperate economical in current and future work processes. In the virtual environment, different forms of human-machine interactions will be integrated and tried out to meet this challenge. Furthermore, the employees can design the interactions, enable a safe environment, and learn a competent handling of robots.

By simulating the working environment, the process can be viewed holistically, designed, and optimized. This does not only affect one, but several highly heterogeneous groups of employees. These include trainees in the dual system of vocational training, as well as semi-skilled employees, skilled employees, and technicians in the form of further training measures. Indirectly, managers in companies are another target group, since they bear the responsibility of deciding on the implementation and type of application of such a concept. In addition to the learner perspective, the teaching and learning concept also takes into account the side of the teacher, which is achieved by supplementing further training or training for teachers and trainers from the school, company, and inter-company learning locations. A train-the-trainer workshop will be developed and conducted with the corresponding target groups. The need for this is demonstrated by various studies, which state that digital media are not used or only used to a limited extent, due to a lack of media competence of teachers or developers of teaching concepts [22].

4. Haptic Feedback

In order to create a realistic representation of the real work processes in the KoRA learning software, one needs to focus on a high degree of immersion. Therefore, the sensory environmental influences should be suppressed as far as possible. Qualitative statements about the degree of immersion can be made, as for example black/white representations are less immersive than color representations, or higher resolutions and beautiful textures appear more real than coarse pixel representations. The more senses are addressed, e.g. by haptic feedback or auditory feedback, the more immersive the virtual environment is. The term "immersion" is distinguished from "presence", which reflects the subjective perception of the user of the virtual environment and differs from person to person. [23]

In order to investigate the haptic feedback that is required, various forms of haptic feedback have been analyzed. As a result, four different forms of feedback are identified as appropriate for the learning environment. An important criterion here is the availability in the consumer marked to ensure a wide applicability in companies and schools. The simplest way is the realization of a haptic feedback through the vibration of a controller. More complex are the integration auf haptic feedback or force feedback gloves. Nevertheless, some products are already available in the consumer market. A fourth form is the integration of real objects via tracker. This makes it possible for the user to grasp and move an object represented in the MR learning software in reality. All four forms of feedback will be tested in specific HRC scenarios and analyzed due to their effect on immersion. The results will be incorporated into the teaching and learning concept, in order to reduce an elaborate implementation of feedback elements [24] to a minimum.

5. Summary

The increasingly small batch sizes due to customer-specifically configured products require a change to flexible production. The HRC offers economic benefit especially in assembly processes. Virtual commissioning also enables a processes validation with the involvement of humans. However, the handling of collaborative robots represents a new challenge for employees over all levels. It is therefore important to train the employees early in the handling of collaborative robots and to involve them in the implementation process. The article describes a concept for a virtual learning application in the field of HRC. The virtual approach enables a safe and quickly adaptable learning environment, in which project-based learn and work assignments are mapped. The digital image of the EMMA research platform forms the basis of the learning environment. The learning factory is already being used in other research projects in the field of collaborative robotics. In the context of the development of the virtual learning environment, a first step is an investigation about the necessity of haptic feedback and its influence on the learning curve. Moreover, survey in education and industry is running that evaluate necessary and realistic learning scenarios.

Acknowledgements

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