Integration of Collaborative Robotics in Vocational Training Using Mixed Reality

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Abstract. The change in production towards smaller batch sizes demands a high degree of flexibility, especially in assembly. In this context, human-robot collaboration (HRC) is becoming increasingly important. The goal is not to displace the human being by the robot, but instead receiving support from it. Nevertheless, employees at all levels have to be prepared for the HRC. Trainings offered from robot manufacturers focus on robot specific operations and are not sufficient for the development of competencies for innovative and creative process planning and optimisation. Therefore, a mixed reality learning environment can be used for the implementation of such training, since real production facilities are only available to a limited extent for training purposes. In the context of the implementation of a mixed reality learning environment, the question arises as to the necessity of haptic feedback. This article presents a concept for integrating HRC in German initial and continuing vocational education and training using mixed reality.

Keywords: Human-Robot Collaboration, Learning Factory, Assembly.

1 Introduction

The importance of flexible assembly is growing in particular due to the increased production of small series through customer-specific productions [1]. The stepwise automation of the production process enables a cost-effective production of customer-specific products. In particular, the design of human-robot collaboration (HRC) plays a central role with regard to future assembly processes, whereby the form of cooperation between human and machine is decisive. The implementation of HRC enables a high overall productivity and a better product quality. [2] However, the safety of the employees showed as a difficult problem [5]. Therefore, the planning of collaborative processes can be supported and validated in a virtual environment [6]. The virtual environment is based on a digital twin using data from new product variants and resource configuration. It allows a simulation of the collaborative processes including the human. The results show, that in order to ensure a safe use of collaborative robots and increase their potential, qualified employees are required. [7] Therefore, employees at all job

levels must be qualified, because it is unlikely that HRC will result in production without employees and it does not represent a desired goal. Rather, the human being remains the most important control and decision-making authority. [3] The aim should be to place the human being at the centre of the process in the sense of designing the work processes [4].

In most cases, the system integrator trains the employees in the use of a specific robot. This training is limited to the teaching of programming knowledge and product-specific basic qualifications. Initial research, as part of the KoRA third-party funding project indicates that these training courses do not meet the expectations from employees in the company. In this context virtual environments offer a safe and reconfigurable learning environment. GAMMIERI ET AL. already published a virtual environment for HRC enhancement [8]. They integrated a forward and inverse kinematic of a KUKA collaborative robot and detected collisions. Furthermore, the digital model can be connected with a real robot. Due to the integration of several collaborative assembly scenarios, the virtual environment can be used for safety considerations as well as for training operators. Another approach from MATSAS AND VOSNIAKOS introduced a virtual reality training system for HRC [9]. The System visualises safety issues like contacts or collisions and can be used to investigate acceptability of HRC. Moreover, OYEKAN ET AL. investigate the reactions from human to movements of the robot [10]. The goal is to test collaborative processes in advance to ensure a safe process. However, none of these approaches provided neither a differentiated learning environment based on the individual qualification level, nor an appropriate teaching concept.

2 Mixed Reality Learning Environment - KoRA

In September 2019, the University of Bremen started a research project named KoRA with the aim to prepare employees at all levels for HRC. The teaching and learning concept enables employees to view complex assembly systems holistically in order to recognise the potential of HRC and use it in a targeted manner. The approach uses a learning software made in Unity in combination with learn and work assignments (see section 3) that rely on the visualisation techniques of Mixed Reality. Within the assignments, the dissolving of rigid borders between manual and automatic assembly is focused by the use of collaborative assembly.

The possibility of participation of the employees offers the potential for dismantling obstacles to collaboration with robots [9]. This is of particular importance because the employees' conviction about the advantages of HRC is a crucial component for the successful introduction into the factory [11]. The complex assembly scenarios are prepared within the framework of learning and work assignments. These take into account operational reality and real work processes and thus enable project-based learning in realistic scenarios. In particular, scenarios on the topics safety, collaboration suitability and technical feasibility are intended (see Fig. 1). The concept addresses trainees, skilled employees and supervisors, as well as trainers and teachers in relation to the German dual vocational training.

Fig. 1. Concept of the KoRA mixed reality training

3 Didactical concept

The didactical concept is based on learn and work assignments (see Fig. 2). They are particularly suitable for dual vocational training due to their occupational world relevance, the link to problematic situations and the project-based learning organisation [12]. Especially, learners benefit from the problems they face in their daily work because the relevance, i. e. the present and future significance (according to KLAFFKI), becomes apparent to them [13].

The learn and work assignments are also characterised by their project form, which promotes the independent development of a problem solution, both as an individual and as a team effort. The acquired knowledge is applied in the development of solutions, the planning of the work steps as well as the implementation and adaption to the individual starting position.

A further advantage of learn and work assignments is the option of flexible design. Heterogeneous target groups identified to be taken into account and to be trained in a targeted manner. The learn and work assignments can be differentiated for the different modes of the learning application and the corresponding learning objectives as well as competence focal points. However, the focus of the gradation is not on the qualification level, but rather on the necessary characteristics of the competence profile for the employees in the collaborative robot environment in the individual company context. The different focal points are magnified in the KoRA learning software in different modes, which have to be selected by the user at the beginning.

Fig. 2. Principle of learn and work assignments (according to HOWE [12])

Besides the employee, the trainer, in school, company and inter-company context, represent another important target group for the concept. They are addressed in train-the-trainer workshops and understood as a central element of the didactic formulation of objectives. In addition to the didactic concept, the trainers are equipped with prepared content and methods for their own teaching and learning context. This lowers the inhibition threshold for the use of the learning software and supports a use beyond the duration of the project.

4 EMMA - Experimental modular assembly plant

The experimental modular assembly plant (EMMA) of the bime Institute consists of six autonomous sub-modules, which can be arranged flexibly (see Fig. 3). Three modules are designed for manual assembly processes and two are fully automated. A collaborative module is used to support another manual assembly station. All assembly stations are connected by a belt conveyor for transportation. The manual stations also have a large touch screen for interactive communication with the employee. This allows, for example, a support for the assembly process to be displayed. As an example product, a ball labyrinth is produced on the plant. This ball labyrinth has been designed in such a way, that it can be dismantled non-destructively. The assembly of the product requires the use of various joining processes, from clips to screws to the knotting of a rope. Together with a variety of possible variations of the product, this results in variable assembly scenarios. The plant as a whole is available as a virtual image and supports a cyber-physical linking between real system and VR environment.

Fig. 3. The experimental modular assembly plant (EMMA)

The collaborative module can be used for several assembly tasks during the production of the ball labyrinth. One possibility is the support during the rack assembly. Within this task, the robot positions the profiles in such a way that the employee can carry out the required screw connections in an optimised manner. The robot is programmed off-line in advance on the basis of CAD data. In practical operation, however, collisions can occur between robots and employees. This can be caused, for example by individual use of the workstation or by the size of the employee. In this case, a hand-guided teach-in of the robot by the employee is necessary in order to adapt the movements of the robot to the respective situation. With the intention of avoiding downtimes in production, the adjustment process must be carried out efficiently by the employee. This scenario can be used as an initial scenario within the virtual learning environment for first investigations about haptic feedback.

5 Haptic Feedback within the learning environment

For a Mixed Reality learning software it is necessary to enable a realistic representation of the virtual environment. Furthermore, the applicability of the hardware solution at the different learning locations is a requirement for the application and its technical implementation. Therefore, the current technological developments and the resulting possibilities and limits have to be considered. The integration of a haptic feedback for the user increases the individual immersion into the scene [14]. This aspect has already been tested in a number of scientific studies. In case of virtual reality training in manufacturing a multi-modal feedback enable effective transfer of virtual acquired knowledge to real-world [9]. However, a corresponding hardware for the consumer market is only available in limited cases. The consumer hardware is regularly limited

to feedback gloves and trackers for tracking physical objects. For the use in the educational system, the simple purchase and a clear integration effort are decisive. The project investigates the necessity and influence of haptic feedback for and on the learning process in a virtual environment. Therefore, a stepwise integration of haptic feedback for different tool classes into the learning software is planned (see Fig. 4). A distinction is made between the following tool classes: static tools (e.g. screwdriver), dynamic tools (e.g. electric screwdriver) and kinematic tools (e.g. Cobot). Moreover, aspects such as human perception, cognitive signal processing and individual visual abilities are taken into account.

Learn and Work Assignments in KoRA

Fig. 4. Experimental setup to evaluate the required haptic feedback

Regardless, it must be investigated under which conditions a higher immersion leads to a higher learning success. This relationship has been investigated particularly in the medical field, where the use of mixed reality is already frequently used in doctor training. RANGARAJAN ET AL. have analysed nine studies where a haptic feedback is used in surgical mixed reality education [15]. They report that six out of the nine studies come to the conclusion that a haptic feedback significantly enhance the simulation and reduces the learning curve. Two studies shows no difference and one study suggested negative effects for training due to decreased realism. RANGARAJAN ET AL. conclude that there can be no general recommendation for the use of haptic feedback. Rather, it must be decided individually for each scenario whether a haptic feedback contributes to the learning success and the additional benefit justifies the costs. [15]

Within the framework of the KoRA project, extensive studies are therefore carried out to determine the required degree of haptic feedback. For this purpose, a first test scenario will be created based on Unity and different levels of haptic feedback will be integrated. On the one hand, physical components will be tracked and integrated into the virtual environment and on the other hand, feedback gloves will be used to simulate contact situations. In order to examine the haptic feedback that is required, the test scenario is first carried out with vocational school classes. The degree of feedback is varied and the learning curve of the participants will be observed. Afterwards, the test will be repeated with employees from companies. Based on these results, the decision of which haptic feedback justifies the associated effort can be evaluated.

6 Summary

This paper describes a concept for a Mixed Reality learning environment that transfers the approach of collaborative robotics into the German initial and continuing vocational education and training. Initial studies indicate that particularly in this area exists a gap in actual teaching and training concepts. The introduced concept is based on the didactical concept of learning and work assignments, which represent project-based and employment-oriented learning. All scenarios within the learning software use an experimental modular assembly plant, which exists as a virtual environment. This allows a stepwise integration of haptic feedback elements to analyse the increase of the learning curve. Afterwards, a decision for each scenario has to be made between the benefits and efforts of feedback elements.

Acknowledgement

The project “KoRA” (“Kompetenzentwicklung zur Gestaltung von Mensch-Roboter-Kollaboration unter Anwendung eines Mixed-Reality-basierten Lehr-Lernkonzeptes”, Grant number 01PV18009) is funded by the German Federal Ministry of Education within the “Digital Media in Vocational Training” programme.

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