WIP: Development of a design framework for the provision of multimodal content in an AR-based training system for the acquisition of psychomotor skills

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Abstract. Augmented reality is a promising technology for vocational training of assembly processes in industry. A field that has received little attention is the application in collaborative assembly, where humans and robots work closely together. Working with a robot increases the complexity of the assembly process and therefore requires effective training. The MILKY-PSY project will investigate, among other aspects, how such immersive training can be implemented for training in collaborative assembly. The development follows the design-based research approach in order to involve the potential user in the early stage. In this work the results of the analysis phase, from three interdisciplinary workshops, are presented. This includes the identification of a specific assembly process, the definition of a training procedure, and the technological requirements for developing such an application. Another important point is the collection of information that should be provided to the trainee for motivated and successful learning. This information can be divided into two categories. Firstly, information that is necessary to complete the specific task and secondly, information that is not directly related to the task but is useful for understanding the task or increasing motivation. These results serve as the basis for a proposed design framework for AR-based training in collaborative assembly presented in this work.

Keywords: Augmented Reality, HRI, Psychomotor Skills, AR-Training, Collaborative Assembly

1 Introduction

Good vocational and further training is essential for companies, but it is also costly and time-consuming. In order to meet the increasing demands on well-trained personnel regarding changes due to the digital transformation, Industry 4.0 and the shift towards more sustainability, learning and training in industrial settings need to shift towards an Education 4.0, too [1]. One possible way to address this is to use Augmented Reality (AR) applications to support learning of assembly processes. Another current trend is the use of robots for collaborative assembly, where humans and machines work closely together. Collaborative robots are increasingly used to support humans in production processes. These so called Cobots can efficiently support humans in assembly tasks. At the same time – mostly in the beginning of trainings, however, they add complexity to the learning of an assembly task. The collaboration with the robot is often not self-explanatory and requires additional training.

The MILKY-PSY project aims to develop an innovative, immersive learning environment for independent learning of psychomotor skills using AI. In the course of the project, applications for two different fields where the training of psychomotor skills is necessary will be developed and tested. One is based in the field of sports and the other in an industrial production environment. This work in progress focuses largely on the application in the production environment, more precisely, in collaborative assembly. The aim is to investigate how the application of an AR training system can support the learning of collaborative assembly processes. Although there are a number of documented examples of AR systems for assembly training [2] [3] [4], there is no application to date for collaborative assembly training with a robot [2]. This work puts a special focus on the training phase, i.e. on teaching a person with no experience to perform a task with a higher repetition rate, rather than on longer-term support. This should enable the trainee to carry out the assembly process independently afterwards, instead of having to wear the head-mounted display for a whole shift for support. In order to develop such immersive learning applications there are a number of procedural models and frameworks for development, however, there is no standardized methodology so far. There also are few approaches to developing immersive learning applications based on models for learning psychomotor skills.

As a work in progress, this paper presents the results of the initial phase of the development of a design framework for the provision of multimodal content in an AR-based training system for the acquisition of psychomotor skills. In a first step, the authors give an insight into the current state of the art regarding AR based training systems and AR applications in robotics. In chapter 3, the authors describe the underlying methodology and present the approach to answering the following research question: How can a framework for an AR-based training system for the acquisition of psychomotor skills in a collaborative assembly scenario be designed in order to increase efficiency and effectiveness in training processes?
In chapter 4, the authors present and analyze the results of the first iterations that directly feed into the development of a preliminary framework (chapter 5) for collaborative assembly training. The final chapter contains a summary of the results to date and provides an outlook on future research.

2 Related Work in AR Assisted Trainings

AR applications in the field of manufacturing have been the subject of research for a several years and there is now a range of work in the field of AR assisted training. This chapter summarizes the current state of AR training for assembly purposes in general, before looking at those specifically for collaborative assembly.

AR Assembly Training Systems

AR applications can add visual and auditory content to the assembly workplace. They allow to provide the learner with useful information at the right moment during an assembly procedure. These in situ instructions allow to reduce the cognitive load of the learner, thus reducing the error rates [6]. This way of presenting information can also be used for independent training of assembly procedures. In this regard it is important to distinguish between a training system and an assistive system. While the assistive system supports in the execution of a task, a training system is concerned with learning a new type of task and repeating it until it can be performed independently. The HMD can be removed as soon as the task has been learned. This has the advantage that not only does the uncomfortable HMD not have to be worn for too long, but Funk [2] have also found that the workers are distracted by the projection once they have mastered the task. They therefore suggest limiting the use of AR in repetitive tasks to the learning phase. Werrlich [3] has developed a design concept for AR supported training and implemented and tested it with an AR application to learn an engine assembly process. Büttner et al. [4] have developed a projection-based AR system and compared it with personal training and paper instructions measuring training times and error rates. They found that personal training leads to the lowest training time and the fewest errors among trainees, but also that trainees using an AR based training still performed better than the ones using a paper version. Another interesting research area is AR based training for collaborative assembly, which is covered in the next section.

AR Training Systems for collaborative Assembly

AR technology has become increasingly interesting for human-robot interaction due to its visualization possibilities. In their review, Makhataeva & Varol [2] give an overview of research on AR applications in robotics. They categorize 100 research papers from 2015-2019 into four areas: (1) medical robotics, (2) motion planning and control, (3) human-robot interaction (HRI) and (4) multi-agent systems. For this work, the HRI category is of primary interest. One of the applications identified is that of Hietanen et al. [6], which presents an augmented reality shared workplace model for safe human-machine interaction. The application found that most resembles the intention of the MILKY-PSY project in this respect is the work of Michalos et al. [7]. They have developed an AR application to help humans interact with a collaborative robot using a mobile device. The focus of the project is on the safety aspect and increased productivity. A case study showed that the tablet used for the implementation proved to be a handicap for humans during the assembly process. Further development for an HMD is therefore necessary in this field.

Although there is already some related work in the field of AR assisted assembly training, AR assisted training for collaborative assembly is still rather rare. Much of the research focuses on safety aspects of human-machine interaction, visualizations and worker support. However, as collaborative assembly is becoming increasingly important in industry, further research is needed.

3 Methodology

The development of technology-assisted training purposes is often accompanied by challenges regarding acceptance and the general use. The need for early involvement of relevant social groups in development processes is now widely recognized. Methods like design based research can be applied in development contexts in order to minimize acceptance issues and improve user experience. "[C]onducting research in context, rather than in a controlled laboratory setting, and iteratively designing interventions" are the underlying principles of the design based research approach in order to gather "authentic and useful knowledge" [2]. Many of the framework models also from the fields of software development and instructional design contain typical phases, e.g. the instructional systems design (ISD) framework ADDIE (Analysis, Design, Development, Implementation and Evaluation). These phases can also be found to some extent in the design based research Framework. For the tasks within the MILKI-PSY project, the design based research model presented by Fraefel [3] has been modified (cf. Figure 1). The iterative processes that allow for constant interplay of theory and practice serve as the methodological foundation of the research and design processes within the project.

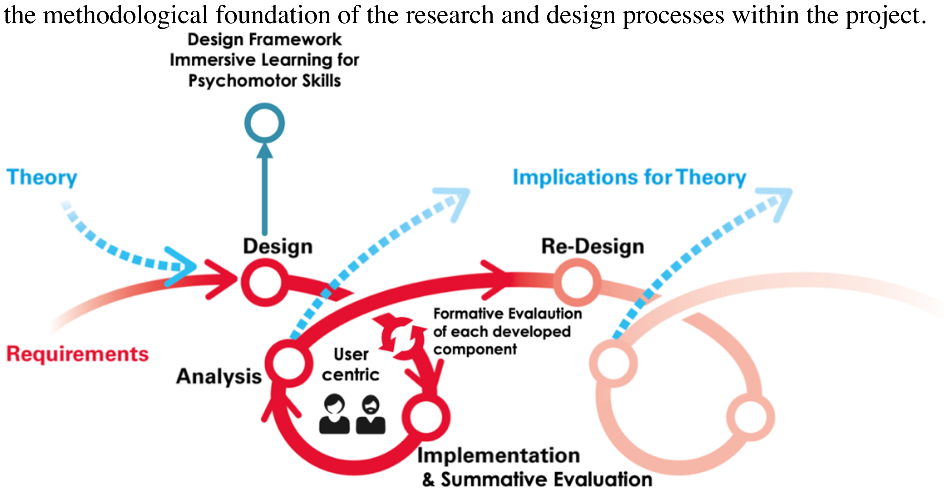

Fig. 1. Design Based Research approach based on Fraefel (2014)

As previously described, the main purpose of this paper is to present the results of the analysis phase and the specification of the framework. Therefore, the analysis of the following important aspects of learning with media namely technology, pedagogy and content as well as their interdependencies is necessary [10]. Aiming to follow a user-centered approach throughout the process, the interdisciplinary consortium worked together in 3 consecutive workshops in order to 1) define the requirements, 2) elicit the theoretical backgrounds and methodological repertoire and 3) develop an initial design framework. The goals and approaches for each of the three workshops are shown in Figure 2. Within the workshops, the interdisciplinary team identified research questions from different disciplines, defined learning outcomes, created a storyboard and lastly specified the training concept and identified necessary developments such as instructional mechanisms and feedback components.

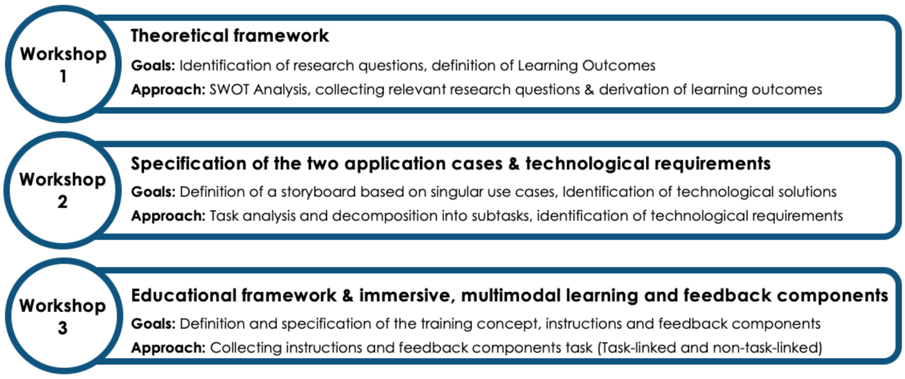

Fig. 2. Structure and contents of the interdisciplinary workshops

The starting point for the user-centric analysis is the identification and specification of a suitable application case. As a result, the collaborative assembly of a sensor case was identified as an application case for the development of the immersive learning environment. Based on the context of use and the requirements analysis an initial theoretical design concept has been developed. In the next section the results of the analysis phase, consisting of the three aspects technology, pedagogy and content are presented.

4 Results of the Analysis Phase

This section presents the results of the analysis phase. First, the outcomes of the three interdisciplinary workshops are presented, which serve as the basis for a design framework for the development of a first prototype.

Content: For the development of the first prototype, a collaborative assembly task was selected in which the trainee assembles a sensor case in collaboration with a robot. Figure 3 illustrates the singular steps of the collaborative assembly task and demonstrates which tasks are to be performed by a robot.

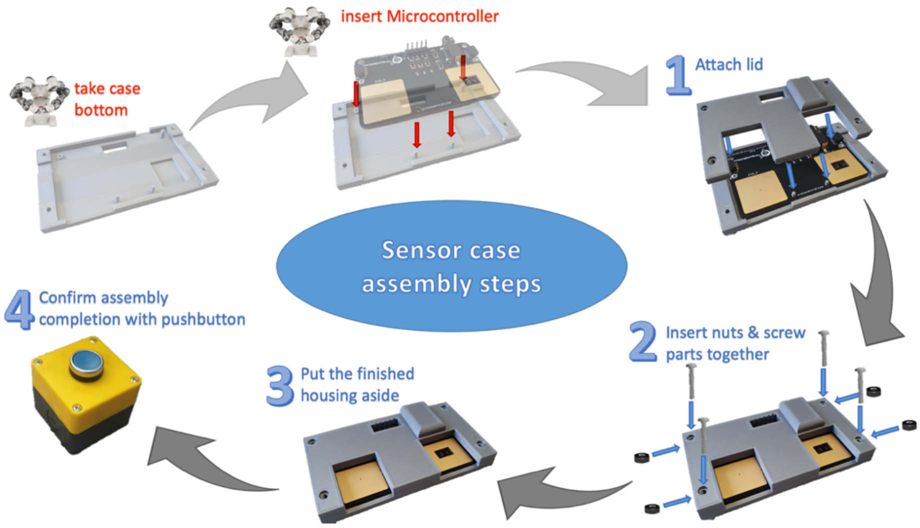

Fig. 3. Sensor case collaborative assembly instructions

Afterwards a decomposition of the assembly procedure into subtasks and elementary activities based on observations of the process was carried out. In addition to the analysis of singular tasks, individual actions and associated failure modes were identified.

Pedagogy: The target group is novices with no or little previous experience with the assembly task and collaborative assembly in general. At the end of the training, the trainee should be able to perform the assembly task independently, without assistance, to understand and anticipate the robot's movements, and to interact with the robot. To do this, the learner must know and be able to perform the elements and procedures required for the task. Training in this case is a process of learning psychomotor skills, which according to Fitts and Posner [7] can be divided into 3 phases which are described in more detail in the next section. This learning model is adapted and used as the basis for the design of the training application.

Technology: A number of hardware and software components are required for the development of the prototype. The selection of these components is partly based on the experience of previous projects, as well as further research from the consortium. In relation to the selected application case, the collaborative assembly, a technology is to be preferred which allows for the operation to be carried out hands-free. Therefore, with regard to the delivery of the multimodal content, the industry-ready HMD Microsoft Hololens has been chosen. In addition, sensors and cameras are required to record the movements and vital parameters of the learners. This data must then be merged and processed before it can be used as the basis for generating the most individualized in-situ guidance and feedback. To meet these demands, Słupczyński & Klamma [13] presented an approach to distributed data analysis of multimodal psychomotor learner activities that will be applied within the project.

Based on the results of this analysis, the authors developed a first draft of a theoretical framework for their first prototype.

5 Theoretical Framework

The design framework proposed in the following aims to summarize and structure all relevant content for the development of an AR-based training system for collaborative assembly. With the Cobot, another component enters the training system that needs to be considered during development. As previously mentioned, the user plays an active part and important role within the entire development process. Based on the results of the three consecutive workshops, a preliminary training procedure has been developed for learning the assembly procedure as shown in Figure 4.

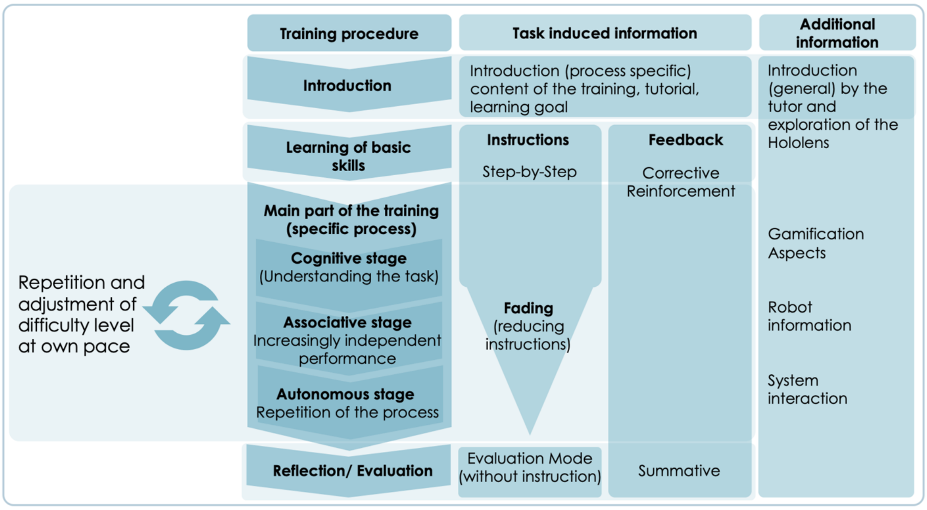

Fig. 4. Theoretical framework for collaborative assembly training

Learning is always linked to a certain prior knowledge. Therefore, basic skills are acquired at the beginning and serve as a basis for the actual process and can be built upon [14]. In order to introduce the learner to the task, general information about the task, the process and the learning objectives should be presented in the first step of the introduction. Since it will probably be the first interaction with a robot for most of the participants, the basic skills for the interaction with the robot will be demonstrated, e.g. by video-based instructions. The acquisition of the skills to perform the actual assembly process is done according to the three phases – cognitive, associative and autonomous phase – presented by Fitts and Posner [7]. It therefore it makes sense to build AR-based training systems according to these phases: For the identified use case in a collaborative assembly process, this means that in the first cognitive phase the assembly process and necessary elements should be understood. In the second, associative phase, declarative knowledge is transformed into procedural knowledge through practical application. More complex motor tasks require repeated execution. In the last phase, the task can be performed without support and without high cognitive effort. The number of times the task needs to be carried out independently depends on the individual's previous experience and the complexity of the task [12]. One way to meet these individual requirements is to adapt the training program individually. For example, the number of repetitions and the support provided can be varied by the trainee. Before the training can be finished, an evaluation is planned at the end to measure the training effect. In addition, a reflection on what has been learned at the end of the learning process will be applied in order to foster deeper understanding. Therefore, the last step is to reflect on what has been learned, but also to evaluate the performance increase and the subjective warning of the trainees.

Once the training process itself has been defined, the next step is to specify the content that may be necessary or helpful to acquire the skill. Throughout the process of collecting the necessary information provided to the learner, it became apparent that there are two different types of information. More precisely, there is information that is necessary or helpful for completing the task and information that does not relate to individual subtasks but is intended to increase overall understanding and motivation. The task-related content is needed for the acquisition of the procedural skills and the required knowledge. The components required for this are, on the one hand, a step-by-step in-situ instruction, which can be derived from the individual subtasks. According to the fading approach, these initially very detailed instructions should be gradually reduced throughout the training process. An important part of learning applications is feedback, for which three types have been identified: On the one hand in the form of a correction for incorrectly executed steps and on the other hand as reinforcement for correctly executed steps. As a conclusion, the trainee can be given summary feedback on the whole process execution.

In addition, information provided, such as approaches from the field of gamification, are intended to increase motivation or serve better contextual understanding, such as the information provided by the robot.

6 Conclusion & Future Research

In this paper, an approach has been presented on how to design a framework for an AR-based training system for the acquisition of psychomotor skills in a collaborative assembly scenario can be designed. For this purpose, a context of use and requirements analysis was first carried out in three workshops. The resulting findings form the foundation for the design framework presented, which in turn serves as the basis for the first design cycle in the development of the prototype in the further course of the MILKY-PSY project. In the course of the development process, the framework should be evaluated and adapted if necessary. In addition, one objective of further research should be how artificial intelligence can be used to develop context-aware AR training systems that come close to the quality of a personal trainer.

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