# motionEAP: An Overview of 4 Years of Combining Industrial Assembly with Augmented Reality for Industry 4.0

**Markus Funk**[1], **Thomas Kosch**[1], **Romina Kettner**[1], **Oliver Korn**[2], **Albrecht Schmidt**[1]

[1]University of Stuttgart (Pfaffenwaldring 5a, 70569 Stuttgart, Germany)
[2]University of Applied Sciences Offenburg (Badstr. 24, 77652 Offenburg, Germany)
firstname.lastname@vis.uni-stuttgart.de[1] – oliver.korn@hs-offenburg.de[2]

## ABSTRACT

With our society moving towards Industry 4.0, an increasing number of tasks and procedures in manual workplaces are augmented with a digital component. While the research area of Internet-of-Things focuses on combining physical objects with their digital counterpart, the question arises how the interface to human workers should be designed in such Industry 4.0 environments. The project motionEAP focuses on using Augmented Reality for creating an interface between workers and digital products in interactive workplace scenarios. In this paper, we summarize the work that has been done in the motionEAP project over the run-time of 4 years. Further, we provide guidelines for creating interactive workplaces using Augmented Reality, based on the experience we gained.

## ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

## Author Keywords

Augmented Reality, Assistive Systems, Industry 4.0, Order Picking, Assembly Workplace

## INTRODUCTION

With the proliferation of Internet of Things (IoT) technology, digital information are becoming more and more integrated into everyday life. Also in manufacturing, digital components are playing a larger role e.g. for quality assurance, configuring products, ordering products, and learning how to produce them. Especially while teaching new workers, technology can make a large impact as it can provide cognitive assistance in the workplace [16].

Starting 2013, the German Federal Ministry for Economic Affairs and Energy funded the project motionEAP[1], which investigated using motion recognition algorithms and Augmented Reality for recognizing a worker's actions and work

---

[1]motionEAP website: **http://www.motioneap.de**

Figure 1. Our system assistive system for the manual assembly workplace uses in-situ projection to provide assembly instructions and uses motion recognition to become context-aware.

steps and further for providing feedback according to the sensed actions directly at the workplace. The consortium consists of industrial partners: Audi AG, Schnaithmann Maschinenbau GmbH, GWW - Gemeinnützige Werkstätten und Wohnstätten GmbH, BESSEY Tool GmbH & Co. KG, KORION Simulation & Assistive Technology GmbH, Robert Bosch GmbH and research partners University of Applied Sciences Esslingen and University of Stuttgart. The project has a run-time until the end of 2016. There are three main aspects of the product life-cycle: manual assembly, order picking, and ethical considerations regarding assistive technology at the workplace. The ethical considerations are described by Behrendt et al. [3]. The contribution of this paper is a summary about the motionEAP project and a set of 8 guidelines that we learned from the manual assembly scenario and the order picking scenario.

## BUILT PROTOTYPES AND CONDUCTED STUDIES

In the context of the motionEAP project, we built different prototypes that investigate a different aspect of using Augmented Reality for cognitive assistance at the workplace. The two large areas are prototypes for manual assembly workplaces and order picking tasks.

### The Manual Assembly Workplace

For augmenting the manual assembly workplace, we built an assistive system using in-situ projection and activity recognition. The system is capable of projecting in-situ instructions for
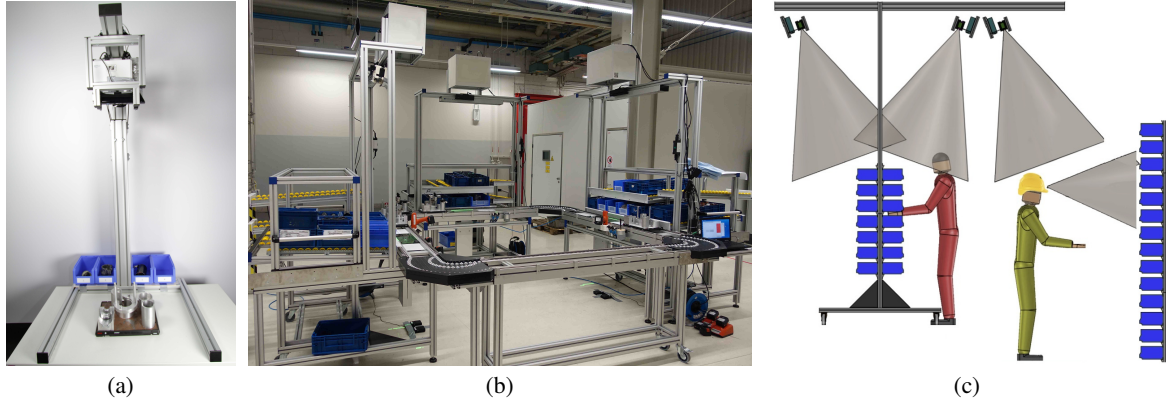
**Figure 2. Four systems that were built in the motionEAP project: a single workplace, a multiuser workplace consisting of three workplaces that are aligned in a U-shape, OrderPickAR - a cart-mounted order picking system, and HelmetPickAR - a user-mounted order picking system.**

communicating the workers how to perform a work step. Simultaneously, the system is capable of recognizing a workers performed actions e.g. picking a part from a bin or assembling a part at the workpiece carrier. The workplace can be used in two ways: as a single workplace (see Figure 2a) or as a multi user workplace (see Figure 2b). Apart from presenting instructions and recognizing assembly steps, our system is e.g. capable of using tangibles as input for digital functions [8], or finding appropriate spots to project the feedback based on the surface suitability [12]. As the user-levels differ from beginner to expert users, we implemented a concept for providing adaptive assembly instructions. The system can provide three levels of visual feedback: beginner mode, advanced mode, and expert mode [5, 7]. For creating instructions, we are using a Programming by Demonstration (PbD) concept, where an expert worker demonstrates how a product is assembled correctly. Afterwards the system automatically generates a visual instruction for beginner and advanced users [9].

We conducted several studies for manual assembly workplaces with both cognitively impaired workers and non-impaired workers. Considering the cognitively impaired workers, we first conducted a study for finding the most appropriate visual instruction visualization [4]. Thereby, we found that a contour-based instruction performs best for all levels of cognitive impairments. Afterwards, we compared haptic, auditory, and visual error feedback [23]. We found that visual error feedback is preferred by the cognitively impaired workers while haptic feedback leads to anxiety among the workers. In another study we found that using our assistive system cognitively impaired workers can assemble products containing up to 48 parts without a noticeable drop in performance [15]. To further motivate the workers, we were experimenting with different gamification concepts to increase worker motivation [18, 19, 20, 21]. Finally, we investigated the long-term impact of in-situ projected instructions on cognitively impaired workers [2].

For workers without impairments, we conducted a study evaluating the instructions created by PbD by comparing them to traditional instructions [13]. Another study focused on finding the best error feedback modality for non-impaired workers,

which revealed that a combination of haptic and visual feedback is the most promising [6].

### Order Picking
In the domain of order picking, we developed three different systems investigating different design dimensions: A stationary system [1], a cart-mounted system called Order-PickAR [17] (see Figure 2c), and a user-worn system called HelmetPickAR [14] (see Figure 2c). All systems have been compared to several state-of-the-art instruction methods.

### A Benchmark for AR Instructions
As a result of our research in using Augmented Reality (AR) for assembly instructions, we introduced a method called General Assembly Task Model (GATM) to evaluate assembly instructions more accurately and provided a reference assembly task [10]. Further, we used our GATM method to compare our assistive system to other AR technologies for providing assembly instructions at the manaual assembly workplace [11].

### LESSONS LEARNED AND GUIDELINES
Based on the experience we gained from using our assistive system in different scenarios and with different user groups, we propose guidelines and recommendations for designing and implementing assistive systems for the workplace. Although these guidelines and recommendations were inspired by using assistive systems at workplace scenarios, we believe that they can be transferred to other scenarios involving assistive systems, e.g. for a smart kitchen scenario (cf. [9]).

### 1. Keep the shown feedback simple:
When designing instructions for assistive systems, two requirements should be considered: First, the instructions should contain all important information that are relevant for the task. Second, the instructions should be as simple as possible. As the two requirements are contrary, the minimum trade-off that still fulfills both requirements needs to be found. In our studies [4, 15], we found that displaying text should be avoided as some workers are not able to read. Also there might be workers with foreign native tongues. Further, we found that videos and complex pictures should also be avoided as they transfer a lot more information than necessary to complete a task. As the

best trade-off between the two requirements, we found that displaying contour information for showing assembly steps is a good way of fulfilling both requirements (see [4]).

**2. Display direct feedback:**
Assistive systems have many possibilities to display feedback and instructions to users. We learned that good feedback should fulfill two requirements: it should be displayed directly at the position where an action is required, and displayed feedback should be context-aware to match the performed actions. When displaying feedback on a screen that is located next to where the actions are performed, users have to transfer the information that is shown on a screen to the real world. This requires cognitive effort and consumes time. In our studies [13, 15], we found that using in-situ projection to display projected feedback directly on the area where the action has to be performed is faster and less cognitively demanding. Secondly, instructions and feedback should be pre-selected based on context. Where in a paper-based reference manual the correct page needs to be found first, an interactive system can select the appropriate feedback or instruction automatically.

**3. Design for hands-free usage:**
Operating an assistive system should not result in additional effort and should not limit the user in performing their tasks. Therefore, we require assistive systems to be designed to enable a hands-free usage. If the user would have to carry a remote controller for interacting with the assistive system, the user's hands would always be occupied by using the controller. We argue for using environment-mounted activity recognition for interacting with assistive systems. For explicitly triggering functions or entering different modes, touch screens or gestures can be used.

**4. Equip the environment rather than the user:**
When analyzing the design space of assistive systems, the dimension of where to put the technology is very important. Assistive systems can be mounted in the environment or can be carried by the user. Also hybrid approaches exist, where assistive systems are both placed away from the user, but the user can carry the technology on demand (e.g. the OrderPickAR cart [17]). Through many studies with expert workers and cognitively impaired workers [4, 13, 15], we recommend to rather equip the environment with technology of the assistive system than equipping users with technology. We learned that users do not want to wear any additional piece of technology when performing a work task. Further, the users sometimes leave the work area to perform other tasks. Then the users would have to take off the technology and put it on again when resuming the task. Also when assistive systems are placed in the environment, multiple users can benefit from it.

**5. Strive for intuitive natural interaction:**
For integrating an assistive system seamlessly into a scenario in the physical world, the interaction with the assistive system also should happen in the physical world. We have to distinguish two scenarios: interacting with the system regularly and programming procedures or workflows for the system. As the users of assistive systems sometimes have problems using a computer or cannot deal with a complex GUI, interaction with the system should happen based on gestures and detecting activity. Further, as designers of assistive systems, we should keep in mind that also users who are teaching workflows or procedures to assistive systems usually do not have a programming background. Although these users are experts in the task they are teaching, does not necessarily mean they are experts in using computers. Therefore, we suggest to also use natural interaction for programming assistive systems.

**6. Design for personalized feedback:**
During our studies, we tried to find the best feedback for both communicating work instructions [4] and for presenting errors [6, 23]. Although we found that a contour visualization of assembly positions is in general the best way to communicate assembly instructions, there were still users that preferred watching an assembly video or looking at pictures of the assembly. Also for communicating errors that occur at the workplace, we found that a combination of visual and haptic feedback is a good trade-off between privacy and error-awareness for non-impaired workers. Despite these results, some users of the assistive system preferred auditory feedback over the visual and haptic feedback. Further, cognitively impaired users liked receiving positive feedback after a work step was performed. As designers of assistive systems, we should take these facts into account. Therefore, a standard feedback should represent the best feedback for the overall population. However, we should provide the opportunity to personalize the feedback that is given and adjust it to the preferences of the users.

**7. Enable users to control the speed:**
Especially when using assistive systems for augmenting work processes, it is important to not rush the user. Instead, the users should be able to perform the steps according to their own pace. This results in one important design decision: all actions that advance instructions or feedback should be triggered by the user and not by the system. Only if the user initiates the process, the user feels in control (cf. [24]). If the system would proceed instructions after a defined amount of time, the system would set the pace of the task. We assume that this would lead to more stress at the workplace. Additionally, for explicitly interacting with the system, e.g. for skipping a work step or for replaying the previous work step, we integrated a foot pedal that can be pressed by the user to control the feedback.

**8. Add motivating quantified-self information:**
Occasionally participants asked how many items were left in the current task and how fast they were. Some participants suggested to have this information always present during their work tasks. This could be as simple as displaying a progress bar which fills up when completing more work steps, or more complex with a leader-board that shows which worker made the fewest errors or produced the most parts. Displaying quantified-self information can be closely linked to adding gamification elements to enhance work processes, which was suggested by Korn et al. [19, 20, 22]. We believe that designing assistive systems in a way that users can always view their quantified-self information will lead to a higher motivation during monotonous tasks when using assistive systems.

**CONCLUSION**
In this paper we presented an overview of the project motionEAP, which focuses on using Augmented Reality for provi-

ding cognitive assistance at the workplace. We summarized the research prototypes that were implemented during the project run-time and provide an overview of the performed studies. Finally, we present a set of eight guidelines to support interaction designers, engineers, and researchers in creating assistive systems for the workplace.

## REFERENCES

1. Andreas Baechler, Liane Baechler, Sven Autenrieth, Peter Kurtz, Georg Kruell, Thomas Hoerz, and Thomas Heidenreich. 2016a. The Development and Evaluation of an Assistance System for Manual Order Picking-Called Pick-by-Projection-with Employees with Cognitive Disabilities. In *Proc. ICCHP'16*. Springer, 321–328.

2. Liane Baechler, Andreas Baechler, Markus Funk, Sven Autenrieth, Georg Kruell, Thomas Hoerz, and Thomas Heidenreich. 2016b. The Use and Impact of an Assistance System for Supporting Participation in Employment for Individuals with Cognitive Disabilities. In *Proc. ICCHP'16*. Springer, 329–332.

3. Hauke Behrendt, Markus Funk, and Oliver Korn. 2015. Ethical Implications Regarding Assistive Technology at Workplaces. In *Collective Agency and Cooperation in Natural and Artificial Systems*. Springer, 109–130.

4. Markus Funk, Andreas Bächler, Liane Bächler, Oliver Korn, Christoph Krieger, Thomas Heidenreich, and Albrecht Schmidt. 2015a. Comparing projected in-situ feedback at the manual assembly workplace with impaired workers. In *Proc. PETRA'15*. ACM, 1.

5. Markus Funk, Tilman Dingler, Jennifer Cooper, and Albrecht Schmidt. 2015b. Stop helping me-I'm bored!: why assembly assistance needs to be adaptive. In *Adjunct Proc. UbiComp'15*. ACM, 1269–1273.

6. Markus Funk, Juana Heusler, Elif Akcay, Klaus Weiland, and Albrecht Schmidt. 2016. Haptic, Auditory, or Visual? Towards Optimal Error Feedback at Manual Assembly Workplaces. In *Proc. PETRA'16*.

7. Markus Funk, Oliver Korn, and Albrecht Schmidt. 2014a. Assisitive augmentation at the manual assembly workplace using in-situ projection. In *Proc. CHI'14 EA*.

8. Markus Funk, Oliver Korn, and Albrecht Schmidt. 2014b. An augmented workplace for enabling user-defined tangibles. In *Proc. CHI'14 EA*. ACM, 1285–1290.

9. Markus Funk, Oliver Korn, and Albrecht Schmidt. 2015. Enabling end users to program for smart environments. *Proc. CHI'15 Workshops* (2015).

10. Markus Funk, Thomas Kosch, Scott W Greenwald, and Albrecht Schmidt. 2015. A benchmark for interactive augmented reality instructions for assembly tasks. In *Proc. MUM'15*. ACM, 253–257.

11. Markus Funk, Thomas Kosch, and Albrecht Schmidt. 2016. Interactive Worker Assistance: Comparing the Effects of Head-Mounted Displays, In-Situ Projection, Tablet, and Paper Instructions. In *Proc. UbiComp'16*.

12. Markus Funk, Thomas Kosch, Katrin Wolf, Pascal Knierim, Sven Mayer, and Albrecht Schmidt. 2016a. Automatic projection positioning based on surface suitability. In *Proc. PerDis'16*. ACM, 75–79.

13. Markus Funk, Lars Lischke, Sven Mayer, Alireza Sahami Shirazi, and Albrecht Schmidt. 2016b. Assistive Augmentation at the Workplace: A System for Creating Semantically-Rich Assembly Instructions. In *Assistive Augmentation: Cognitive Science and Technology (to appear)*. Springer.

14. Markus Funk, Sven Mayer, Michael Nistor, and Albrecht Schmidt. 2016. Mobile In-Situ Pick-by-Vision: Order Picking Support using a Projector Helmet. In *Proc. PETRA'16*, Vol. 4.

15. Markus Funk, Sven Mayer, and Albrecht Schmidt. 2015. Using In-Situ Projection to Support Cognitively Impaired Workers at the Workplace. In *Proc. ASSETS'15*. ACM, 185–192.

16. Markus Funk and Albrecht Schmidt. 2015. Cognitive assistance in the workplace. *IEEE Pervasive Computing* 14, 3 (2015), 53–55.

17. Markus Funk, Alireza Sahami Shirazi, Sven Mayer, Lars Lischke, and Albrecht Schmidt. 2015. Pick from here!: an interactive mobile cart using in-situ projection for order picking. In *Proc. UbiComp'15*. ACM, 601–609.

18. Oliver Korn, Markus Funk, Stephan Abele, Thomas Hörz, and Albrecht Schmidt. 2014. Context-aware assistive systems at the workplace: analyzing the effects of projection and gamification. In *Proc. PETRA'14*. 38.

19. Oliver Korn, Markus Funk, and Albrecht Schmidt. 2015a. Design approaches for the gamification of production environments: a study focusing on acceptance. In *Proc. PETRA'15*. ACM, 6.

20. Oliver Korn, Markus Funk, and Albrecht Schmidt. 2015b. Towards a gamification of industrial production: a comparative study in sheltered work environments. In *Proc. EICS'15*. ACM, 84–93.

21. Oliver Korn, Peter Muschick, and Albrecht Schmidt. 2016. Gamification of Production? A Study on the Acceptance of Gamified Work Processes in the Automotive Industry. In *Proc. AHFE'16*.

22. Oliver Korn, Albrecht Schmidt, and Thomas Hörz. 2013. The potentials of in-situ-projection for augmented workplaces in production: a study with impaired persons. In *CHI'13 EA*. ACM, 979–984.

23. Thomas Kosch, Romina Kettner, Markus Funk, and Albrecht Schmidt. 2016. Comparing Tactile, Auditory, and Visual Assembly Error-Feedback for Workers with Cognitive Impairments. In *Proc. ASSETS'16*. ACM.

24. Ben Shneiderman. *Designing the user interface: strategies for effective human-computer interaction*. Vol. 3.