One Size does not Fit All - Challenges of Providing Interactive Worker Assistance in Industrial Settings

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Abstract
Teaching new assembly instructions at manual assembly workplaces has evolved from human supervision to digitized automatic assistance. Assistive systems provide dynamic support, adapt to the user needs, and alleviate perceived workload from expert workers supporting freshman workers. New assembly instructions can be implemented at a fast pace. These assistive systems decrease the cognitive workload of workers as they need to memorize new assembly instructions with each change of product lines. However, the design of assistive systems for the industry is a challenging task. Once deployed, people have to work with such systems for full workdays. From experiences made during our past project motionEAP, we report on design challenges for interactive worker assistance at manual assembly workplaces as well as challenges encountered when deploying interactive assistive systems for diverse user populations.

Author Keywords
Augmented Reality; Worker Assistance; Industry 4.0; Assembly Workplace

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H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

motionEAP [8] was a project funded by German Federal Ministry of Economic Affairs and Energy. The project investigated the effect of using in-situ projections as a substitute for traditional paper instructions or personal supervisors. Assembly instructions were either displayed using in-situ projections or through head-mounted displays. The target groups were freshman workers and expert workers in the industry as well as cognitively impaired workers that are employed in sheltered work organizations.

Introduction and Background

Providing assembly instructions at workplaces is a major challenge for industrial settings. This is fostered by companies producing their products in small lot sizes, which results in workers needing to assemble different products very frequently. As there is a huge variance in the manufactured products, this also increases the overall complexity of learning the assembly of new product lines. Traditionally, new workers get an introduction from more experienced colleagues [14] or use paper instructions. However, experienced colleagues are not always available and paper instructions are easily outdated and have to be switched for each change in the currently assembled product. Additionally, new instructions have to be memorized, which may have a significant impact on the workers' performance [11]. As an alternative to present solutions, interactive technical solutions have been proposed. Usually, three groups of assistance technology are used to visualize assembly instructions comprising regular displays [10], Head-Mounted Displays (HMDs) [9, 15], and in-situ projections [2]. A comprehensive summary of Augmented Reality assistance for assembly processes is provided by Büttner et al. [3].

Nonetheless, instructions have to be suited adaptively to the target user population [7]. While new workers rely on the knowledge of experienced workers [1], experienced workers do not need help at all when assembling on new production lines. After new workers are familiar with novel assembly lines, instructions are usually not needed anymore [6]. However, current instruction systems are not aware of this learning stage and might provide undesired instructions in scenarios where there is no help needed [7].

In contrast, persons with cognitive impairments who are employed in sheltered working organizations traditionally require permanent supervision by a human instructor. Understandable digitized assembly instructions helped to relieve the workload of supervisor in past research [5, 10].

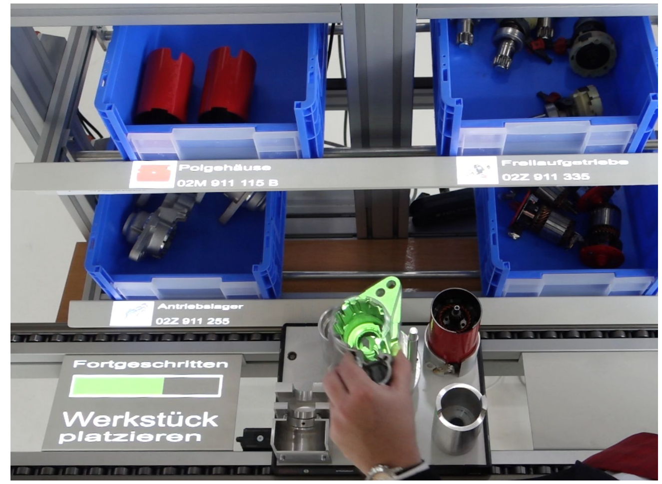

Figure 1: Assembly of an engine starter using in-situ projections. Assembly instructions are displayed into the field of view of the worker. Image source: [8].

We present research outcomes concerning in-situ based instructions for different types of user groups, including freshmen workers and experienced workers in companies as well as workers with cognitive impairments employed in sheltered work organizations. Based on our experiences that we made in our project "motionEAP[1]", we report on obstacles and design challenges being experienced when providing instructions using in-situ instructions for specific user groups (see Figure 1). We conclude with suggested solutions for design challenges, which have been faced during the course of our research project.

[1] www.motioneap.de

User Populations

A wide range of user groups has been involved in the evaluation of assembly instructions. Due to differences between groups, the design requirements were seldom the same. We define three different user groups, which were the subject of evaluation. As the system that is providing the instructions, we used a projector that was mounted on top of a workplace. Further, a depth sensor validates the performed work steps and provides feedback for each performed work step.

Freshman Worker

Freshman workers are at the beginning of their employment and do not have much experience in assembly tasks. Such workers are often employed without any prior knowledge in this field. Traditionally, freshman workers learn from more experienced colleagues how assembly tasks are performed. Alternative solutions are paper instructions, which help to learn the basic assembly concepts of the currently assembled product.

Experienced Worker

In contrast to the freshman workers, expert workers testify several years of assembly experience. They act as first persons learning assembly steps to transfer their knowledge to the freshman workers.

Cognitively Impaired Worker

Cognitively impaired workers mostly have mental deficiencies and are thus employed at sheltered work organizations. They require continuous personal assistance, even when they are familiar with the assembly task. This is usually accomplished by a personal instructor, which is responsible for multiple persons. Implicitly, the workload of the instructor increases with the number of persons which must be supervised.

Design Challenges for Specific User Groups

With the defined user groups, the impact of in-situ instructions during assembly has been investigated. This includes the revelation of design drawbacks when presenting in-situ projected instructions to workers. We report encountered design failures when evaluating in-situ projected feedback as assembly instructions for each of the previously described user groups.

Freshman workers benefit from in-situ projected instructions to learn how to assemble a workpiece for the first time [6] (see Figure 2). A long-term study revealed slower assembly times while using in-situ projected instructions. After removing the in-situ projected instructions, participants were assembling faster while having a reduced error rate. However, workers were distracted by projections after a number of assembly cycles. After familiarizing with the new workpiece, in-situ projected instructions were perceived as obtrusive. Participants reported that the light distracted them after the initial learning phase [6]. Assembly instruction adaptation is a way to cope with distractions through overassistance [7].

Experienced workers perceive in-situ instructions as distracting throughout the usage. Through a long-term study of using in-situ instructions in an industrial setting [6], expert workers noted that understanding in-situ instructions require additional cognitive effort, thus yielding an additional cognitive component. A higher task completion time and increased subjectively measured workload testified these statements. However, they stated that such systems can relieve their workload when it comes to assisting freshman workers.

In contrast, **cognitively impaired workers** showed best assembly performances when receiving continuous support by in-situ instructions [5, 10] (see Figure 3). While most

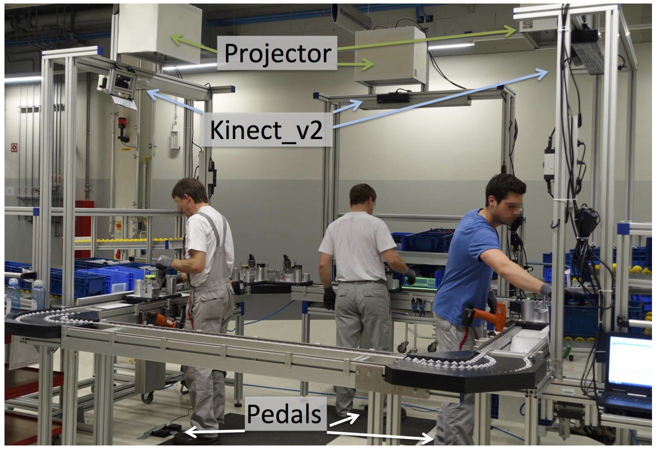

Figure 2: Workers assembling an engine starter in an U shaped assembly line. In-situ instructions slowed workers down and were perceived as obtrusive. Image source: [6].

Figure 3: Worker assembling a clamp in a sheltered work organization using in-situ projection assistance. Continuous in-situ assembly instructions were perceived as helpful.

cognitively impaired workers are able to perform few work steps without any support, in-situ instruction provides cognitive alleviation which makes cognitively impaired workers capable of assembling complex constructions that consist of up to 48 parts [10]. Studies on using gamification in working environments showed positive results [12]. Motivation and efficiency of workers with cognitive deficiencies were held high constantly through the assembly. Visual in-situ projections also showed best feedback performance compared to auditory and tactile feedback [13]. Additionally, minor privacy concerns were raised regarding the usage of in-situ projections at workplaces. Auditory feedback was perceived as annoying, while tactile feedback showed to be disturbing to an extent, which impacts the overall worker's performance.

Lessons Learned

We present the lessons learned regarding the design of in-situ projected instructions for different user groups. Our findings imply, that inexperienced workers benefit from assembly instructions at the learning stage at the cost of assembly completion time. However, after the learning stage, in-situ projected instructions were perceived obtrusive. This can be tackled by providing adaptive assembly instructions [4, 7]. For instance, projections can be turned off when a number of correct steps have been recognized. At the same time, a depth camera can monitor errors and notify the projection system to provide in-situ instructions when help is needed.

Cognitively impaired persons have shown positive observations when using in-situ projected instructions. Task completion time and the error rate has decreased significantly.

Furthermore, regular work was carried out over a long timespan. Visual feedback has proved to be most beneficial for providing assembly instructions [13]. However, tactile and auditory feedback was perceived as disturbing by cognitively impaired workers. Most participants argued, that the stimuli were not common to them. A long-term study in a sheltered work organization using the stated stimuli will show if a learning effect for the output modalities can be observed.

Conclusion

This workshop paper presents how different user groups are affected by projected in-situ instructions at manual assembly workplaces. We define the three user groups freshman workers, experienced workers, and workers with cognitive disabilities as a target population. Furthermore, we explain for which groups in-situ projection were beneficial or a hindrance. While workers with cognitive disabilities benefit from permanent support, experienced and freshman workers only benefit during their learning phase from assistance at workplaces. We conclude that continuous support is necessary for workers with cognitive impairments. However, adaptive instructions are required for freshman and expert workers.

The design and implementation of assistive systems in smart factories impact the efficiency and performance of workers. The system design has to be verified thoroughly before applying it to production facilities. Suited interactive worker assistance yields the potential to increase the productivity while reducing error rates. However, finding an efficient design during the first iteration is seldom and should be evaluated and reviewed carefully. The effect on the ecosystem must be observed before applying it to real production facilities.

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References

[1] John Robert Anderson. 2000. Learning and memory. (2000).

[2] Alexander Bannat, Frank Wallhoff, Gerhard Rigoll, Florian Friesdorf, H Bubb, Sonja Stork, HJ Müller, Anna Schubö, Mathey Wiesbeck, Michael F Zäh, and others. 2008. Towards optimal worker assistance: a framework for adaptive selection and presentation of assembly instructions. In *Proceedings of the 1st international workshop on cognition for technical systems, Cotesys*.

[3] Sebastian Büttner, Henrik Mucha, Markus Funk, Thomas Kosch, Mario Aehnelt, Sebastian Robert, and Carsten Röcker. 2017. The Design Space of Augmented and Virtual Reality Applications for Assistive Environments in Manufacturing: A Visual Approach. In *Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments*. ACM, 433–440.

[4] Mai ElKomy, Yomna Abdelrahman, Markus Funk, Tilman Dingler, Albrecht Schmidt, and Slim Abdennadher. 2017. ABBAS: An Adaptive Bio-sensors Based Assistive System. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. ACM, 2543–2550.

[5] Markus Funk, Andreas Bächler, Liane Bächler, Oliver Korn, Christoph Krieger, Thomas Heidenreich, and Albrecht Schmidt. 2015. Comparing Projected In-Situ Feedback at the Manual Assembly Workplace with Impaired Workers. In *Proceedings of the 8th International Conference on PErvasive Technologies Related to Assistive Environments*. ACM, New York, NY, USA. DOI:

http://dx.doi.org/10.1145/2769493.2769496

[6] Markus Funk, Andreas Bächler, Liane Bächler, Thomas Kosch, Thomas Heidenreich, and Albrecht Schmidt. 2017. Working with Augmented Reality? A Long-Term Analysis of In-Situ Instructions at the Assembly Workplace. In *Proceedings of the 10th ACM International Conference on PErvasive Technologies Related to Assistive Environments*. ACM, New York, NY, USA. DOI:http://dx.doi.org/10.1145/3056540.3056548

[7] Markus Funk, Tilman Dingler, Jennifer Cooper, and Albrecht Schmidt. 2015. Stop Helping Me - I'm Bored! Why Assembly Assistance needs to be Adaptive. In *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM. DOI:http://dx.doi.org/10.1145/2800835.2807942

[8] Markus Funk, Thomas Kosch, Romina Kettner, Oliver Korn, and Albrecht Schmidt. 2016b. motioneap: An overview of 4 years of combining industrial assembly with augmented reality for industry 4.0. In *Proceedings of the 16th International Conference on Knowledge Technologies and Datadriven Business*.

[9] Markus Funk, Thomas Kosch, and Albrecht Schmidt. 2016a. Interactive Worker Assistance: Comparing the Effects of In-situ Projection, Head-mounted Displays, Tablet, and Paper Instructions. (2016), 934–939. DOI:http://dx.doi.org/10.1145/2971648.2971706

[10] Markus Funk, Sven Mayer, and Albrecht Schmidt. 2015. Using In-Situ Projection to Support Cognitively Impaired Workers at the Workplace. In *Proceedings of the 17th international ACM SIGACCESS conference on Computers & accessibility*. ACM. DOI:http://dx.doi.org/10.1145/2700648.2809853

[11] Markus Funk and Albrecht Schmidt. 2015. Cognitive Assistance in the Workplace. *Pervasive Computing, IEEE* 14, 3 (July 2015), 53–55. DOI:http://dx.doi.org/10.1109/MPRV.2015.53

[12] Oliver Korn. 2012. Industrial Playgrounds: How Gamification Helps to Enrich Work for Elderly or Impaired Persons in Production. In *Proceedings of the 4th ACM SIGCHI Symposium on Engineering Interactive Computing Systems (EICS '12)*. ACM, New York, NY, USA, 313–316. DOI:http://dx.doi.org/10.1145/2305484.2305539

[13] Thomas Kosch, Romina Kettner, Markus Funk, and Albrecht Schmidt. 2016. Comparing Tactile, Auditory, and Visual Assembly Error-Feedback for Workers with Cognitive Impairments. In *Proceedings of the 18th international ACM SIGACCESS conference on Computers & accessibility*. ACM. DOI:http://dx.doi.org/10.1145/2982142.2982157

[14] GI McCalla, JE Greer, VS Kumar, P Meagher, JA Collins, R Tkatch, and B Parkinson. 1997. A peer help system for workplace training. *Artificial Intelligence in Education: Knowledge and Media in Learning Systems* (1997), 183–190.

[15] Xianjun Sam Zheng, Cedric Foucault, Patrik Matos da Silva, Siddharth Dasari, Tao Yang, and Stuart Goose. 2015. Eye-Wearable Technology for Machine Maintenance: Effects of Display Position and Hands-free Operation. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 2125–2134. DOI:http://dx.doi.org/10.1145/2702123.2702305