The Potentials of In-Situ-Projection for Augmented Workplaces in Production. A Study with Impaired Persons

Abstract
Interactive projections have been around for more than a decade. We measured their potentials for augmented workplaces in production. For this purpose we built the prototype of an assistive system projecting instructions directly into the workspace (in situ). While it can be applied in every production environment, the system was first implemented and tested where it is needed the most: in a sheltered work organization employing persons with impairments.

It could be shown that the assembly times could be slightly reduced by the augmented system. However it had a “catalytic” effect on the test subjects’ work quality: While some seem to be overwhelmed by the new information density and perform worse, others perform much better than the control group and significantly reduce error rates. The qualitative results show that although impaired persons retain a critical perspective on systems directly changing the way they have been working for years, all users would like to retry working with the system. When looking at additional aids like the projection of a real-sized model in the workspace, the users invariantly accept its benefits for their assembly work.

Oliver Korn 1,2 oliver.korn@acm.org
Albrecht Schmidt 1 University of Stuttgart, VIS, Pfaffenwaldring 5a 70569 Stuttgart, Germany albrecht.schmidt@vis.uni-stuttgart.de
Thomas Hörz 2 University of Applied Sciences Esslingen, Kanalstr. 33, 73728 Esslingen, Germany thomas.hoerz@hs-esslingen.de

Copyright is held by the author/owner(s).
ACM 978-1-4503-1952-2/13/04.
Introduction
The market for manual production work with impaired persons becomes increasingly important. This is mainly due to two reasons: (1) Most companies are legally obliged to employ a certain percentage of disabled and impaired persons. This often is met by contracting “sheltered work” organizations which focus on providing adequate work conditions for them. (2) The increased cost and time requirements when outsourcing production to remote locations impede lean production, so the regional alternatives become more attractive.

Sheltered work organizations have long ceased to provide “occupational therapy” but offer modern work conditions and manufacture increasingly complex products. They also are subject to rising customer demands like just-in-time deliveries and build-to-order products. While classic production companies are reluctant to implement and test new forms of Human Machine Interaction (HMI), organizations working with impaired persons have always been working with new assistive technology and are keen on improving their processes and broadening their product range. In our previous research [3, 4] we established the following requirements for augmented assistive systems in productions environments (aASiPE):

- increased process-orientation
- simplified user interfaces (UI) and support for natural interaction
- implementation of motivating elements

We present first results of a study analyzing the effects of in-situ projection on work (time, quality) and on workers (perceived usability, acceptance). For this purpose we built the prototype of an aASiPE meeting the first and the second requirement.

Related Work
With the success of smartphones and wearable sensors ubiquitous computers “weaving themselves into the fabric of everyday life” [10] have become reality. Interactive projections are an important part of this concept because they enable the augmentation of the real world by computer visuals. However for projections to become interactive, additional equipment like video cameras or depth-sensing range sensors are required.
One of the first systems successfully combining projection with interaction and thus pioneering “natural interaction” was the 2001 Everywhere Displays projector [8]. It employed a video camera to detect hand interaction with a projected image. The system’s intended use was collaborative work in meeting rooms, but the high amount of calibration it required prevented its pervasion beyond the scope of scientific use. The idea of interactive projections was furthered by improving mobility accuracy and latency [6].

In 2010 a study first evaluated the effectiveness of augmenting on-screen instructions with micro-projection for manual task guidance [9]. It focused on everyday tasks performed by un-impaired users and showed that the augmented instructions improved overall participants’ performance.

Lately miniaturized pico projectors have even been investigated as mobile displays and interaction devices or "light beams", weaving themselves even more into the fabric of everyday life by turning everyday objects into projection surfaces and interaction devices [2].

The focus of this related work mostly has been office use, entertainment or mobile computing. While there obviously is much work on interactive projection in the field of computer science, this differs with engineering. While light barriers are frequently used in assembly tables to control "picks" (the process when a worker takes an assembly part out of a box) more recent forms of HMI are integrated into productive systems at a slow rate. A 2011 Fraunhofer study on HMI [1] even states that from the variety of modern interaction techniques only touch screens found their way to common machine interfaces in production environments.

Design of the Study
The study was conducted to empirically observe and analyze how impaired workers in production are affected by an assistive system with increased process-orientation, simplified UI and natural interaction. To be able to observe this, a prototypical aASiPE using in-situ projection was constructed (Figure 1). It consists of a simplified assembly table and uses the software ASED (Assistant Systems Experiment Designer), described in previous work [5]. It uses motion recognition to monitor pre-defined interactive areas (Figure 2: six areas to check “picks” and two areas to move back and forward through the instruction) and thus allows the automatic logging of the assembly process.

The study was conducted at the Beschützende Werkstätte Heilbronn (BWH), a German sheltered work organization supervising about 1,000 workers suffering from various kinds of cognitive and / or motoric impairments ranging from permanent stroke damages to epilepsies. While (almost) all of them are able to eat on their own or express thoughts in simple words, their competence levels vary considerably: some would not be able to count to ten while others are capable of performing basic algorithmic operations. A similar variance occurs with regard to assembly skills. Although the aASiPE has been designed to assist as many impaired persons as possible, our first task was to narrow down the population of test subjects by isolating those who are principally capable of simple assembly tasks.

In a pre-study impaired workers with varying competence levels had to assemble simple products. The resulting minimal requirement was being able to assemble a product consisting of four Lego pieces.
This requirement narrowed down the number of test subjects from 100 (who had consented to participate in the study) to 81. The test population then was divided into three groups or settings (Figure 4, 5) with a similar distribution of competences and working experience:

1. state-of-the-art ASiPE (SotA)
2. ASiPE augmented by in-situ projection (in-situ)
3. ASiPE augmented by motivating elements (third requirement, analyzed in future work)

The 40 test subjects in group 1 and 2 were asked to assemble eight identical car undercarriages consisting of nine Lego bricks (Figure 3), so each assembly required eight processes. While the image-based instructions remained identical, they were displayed on a monitor for the SotA group and projected directly onto the working plate for the in-situ group. Since the term "state-of-the-art" reflects industry standards, already the SotA group had to cope with a small change of medium because in their normal workspace instructions mostly are printed on paper.

On the quantitative level (which is still being analyzed) the work action themselves were measured – reflected by process times and process quality. For the analysis we used the ASED log files, videos and photos of the resulting products.

On the qualitative level we measured the attitude towards work focusing on acceptance and usability. We used a questionnaire where the test subject had to agree or disagree on assertions using a bipolar scale with 5-level Likert items (exactly right; right; neutral; not right; not right at all) based on an adapted version of the SUS system usability scale [7]. Some of the assertions deliberately were redundant to eliminate systemic statistical error sources.

**Study Results**

An average experiment in the SotA group took 25.6 minutes (standard deviation SD = 9.0 minutes) with an average error rate of 22.6% (SD = 17.5%). The in-situ group was slightly faster (23.6 minutes, SD = 10.3 minutes) but produced 6.5% more errors (29.1%, SD 27.3%). Although the analysis of the quantitative results is ongoing, these early results are surprising – after all in-situ projection was seen as a way to minimize cognitive effort and thus reduce not only process times but also error rates.

An in-depth analysis showed that compared to the rather homogenous SotA group (SD significantly lower), the in-situ group was divided into two sub-groups: while twelve impaired persons responded well to the augmentation, the other eight persons responded so badly that they performed worse than usual. The latter were producing an extremely high error rate of 50.8% (SD = 27.4%) while the "well-responders" produced an error rate of only 14.7% (SD = 15.5%). For the success of assistive systems using in-situ projection it is crucial to either restrict their use to the "well-responders" or find the reasons, why 40% of the test subjects are producing more waste than before.

Based on these interim results from the quantitative analysis we now portray the qualitative results. The basic assertions (a) tested were whether the use of the ASiPE was easy (a1) or complicated (a2). Since usability is an essential concept, both were tested to rule out the tendency towards affirmative answers.
In the SotA group the average response was $\bar{a}_1 = 1.9$ (SD = 0.4) so the system was considered easy to use, and $\bar{a}_2 = 4.3$ (SD = 0.9) on the contrary question. The answers to the opposing questions are consistent. The same can be said about the in-situ group. However, here the answers are $\bar{a}_1 = 2.4$ (SD = 0.7) and $\bar{a}_2 = 4.0$ (SD = 0.5), so the perception of the system’s usability slightly decreased ($\Delta_{a1} = 0.5$ and $\Delta_{a2} = 0.3$). This finding contradicts the intuition that in-situ projection will be perceived as an improvement – but it complies with the quantitative findings on the error rate and the group’s division. Indeed the correlation coefficient ($r$) between the answers $a_1$ and the individual error rates is $r = 0.2$ (SotA) versus $r = 0.4$ (in-situ). This indicates that errors made in the in-situ system were more readily attributed to the new system as with the SotA system.

The next assertions examined are “I would use the AS again” ($a_3$) and “I would recommend the AS to my colleagues” ($a_4$). In the SotA group the average responses were $\bar{a}_3 = 1.9$ (SD = 0.7) and $\bar{a}_4 = 1.8$ (SD = 0.5) so the subjects were positive. In the in-situ group the average responses were $\bar{a}_3 = 2.0$ (SD = 0.6) and $\bar{a}_4 = 2.4$ (SD = 0.7) so the acceptance of the new system is better than its attributed usability. From our interviews we know that impaired workers are open to innovation; so although they looked critical at their own performance with in-situ projection they still seem to consider it potentially helpful.

A benefit of in-situ projection is not having to look up at the monitor for checking instructions. This was tested by the assertions “It was tedious to continuously check the instructions on the monitor above me” ($a_5$, SotA) and “I liked having instructions directly next to me on the table” ($a_6$, in-situ). In the SotA group the average response was $\bar{a}_5 = 3.9$ (SD = 0.9) so most subjects did not complain about having to change the view focus. In the in-situ group the average response was $\bar{a}_6 = 2.0$ (SD = 0.3), so with very little variation instructions in proximity were seen favorably. Another potential advantage was the real-sized model of the current part projected in the center of the workspace. This aid’s acceptance was tested with the assertion $a_7$ “The model in the center of my workspace was helpful”. The average response was $\bar{a}_7 = 2.0$ (SD = 0.2) so it was considered helpful. The approval rate had the lowest variation within the whole survey (followed by $a_6$).

**Discussion, Conclusion and Future Work**

Impaired persons, although open to innovations, retain a critical perspective on systems directly changing the way they work. They need time to adapt to changes, so many subjects considered new system with projection to be more difficult and accordingly mistakes were more readily attributed to it. On the other hand all users would like to retry the system. When looking closely at new aids like the additional real-sized model the users almost invariably agree on the benefits.

The augmented assistive system has a “catalytic” effect on the test subjects’ work quality: While some perform worse, others perform much better than the control group and significantly reduce error rates. For the success of ASiPE augmented by in-situ projection it is crucial to either restrict their use to these users – or to find the reasons why the other 40% are producing more waste than before in future research. A possible explanation is that the 40% who could not cope are just slower learners and would have needed more time to get used to the new form of instruction.
Future research includes a long-term study with the current system, a new study on the third requirement for future ASiPE (implementation of motivating elements) measuring the effects of gamification on users and work; subsequently we plan a study quantifying the effects of both augmentations (in-situ projection and gamification) on un-impaired workers.

Acknowledgements
Our thanks go to the Beschützende Werkstätte Heilbronn for supporting the experiments and to the company Schnaithmann GmbH for building the experimental assembly table.

References