Using In-Situ Projection to Support Cognitively Impaired Workers at the Workplace

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ABSTRACT

Today's working society tries to integrate more and more impaired workers into everyday working processes. One major scenario for integrating impaired workers is in the assembly of products. However, the tasks that are being assigned to cognitively impaired workers are easy tasks that consist of only a small number of assembly steps. For tasks with a higher number of steps, cognitively impaired workers need instructions to help them with assembly. Although supervisors provide general support and assist new workers while learning new assembly steps, sheltered work organizations often provide additional printed pictorial instructions that actively guide the workers. To further improve continuous instructions, we built a system that uses in-situ projection and a depth camera to provide context-sensitive instructions. To explore the effects of in-situ instructions, we compared them to state-of-the-art pictorial instructions in a user study with 15 cognitively impaired workers at a sheltered work organization. The results show that using in-situ instructions, cognitively impaired workers can assemble more complex products up to 3 times faster and with up to 50% less errors. Further, the workers liked the in-situ instructions provided by our assistive system and would use it for everyday assembly.

Author Keywords

Augmented Reality; Assistance for Impaired Workers; Assistive System; In-Situ Projection

ACM Classification Keywords

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

INTRODUCTION

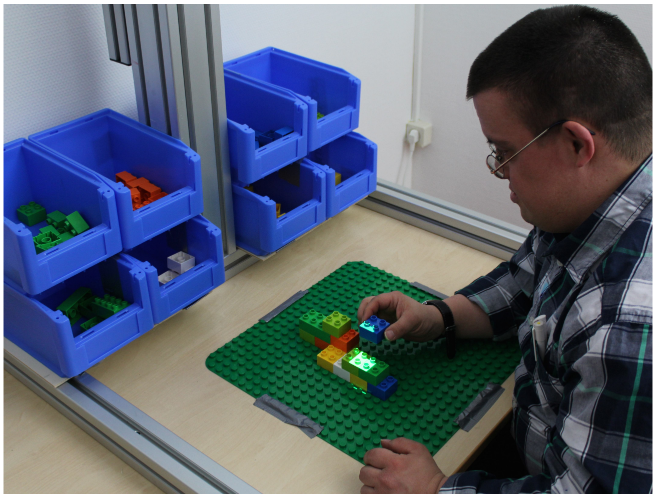

Figure 1. A participant is assembling Duplo bricks using in-situ projected instructions provided by our assistive system.

Projectors are becoming more common and are widely available. One of the reasons for this is the operational flexibility because they can displaying content on nearly any surface. Projected content can even be automatically adjusted to the projection surface by combining the projector with a camera [13] rendering the projection distortion free. This technology can also be applied to provide instructions at the workplace where the instructions can be projected directly onto the workers field of view [7] (see Figure 1). These so-called in-situ instructions do not require the worker to focus on an external screen or on a printed manual anymore and can keep the focus on the task while viewing instructions. The technique of using in-situ projection for instructing workers is already used in some commercial approaches. For example Light Guide Systems[1] use a top-mounted projector to display the next working step. Another commercial system such as the WERKLICHT from Extend3D[2] is using a laser projector to highlight important points for assembly.

Such assistive systems offering in-situ instructions at the working place can substantially increase the inclusion of impaired workers into the working life [1]. Moreover, these assistive systems open a variety of ways to employ impaired workers, as impaired workers are enabled to work on increasingly complex products when continuously receiving instructions [17]. This additionally fosters the inclusion of impaired workers

ASSETS'15, October 26–28, 2015, Lisbon, Portugal.

ISBN 978-1-4503-3400-6/15/10$15.00
DOI: http://dx.doi.org/10.1145/2700648.2809853

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[1] Light Guide Systems - `http://www.ops-solutions.com` (last access 05-07-2015)

[2] WERKLICHT - `http://www.extend3d.de/en/products/wl_pro/` (last access 05-07-2015)

into company's daily business and increases the productivity in sheltered work organizations.

New research in assistive systems for impaired workers focuses on adding gamification approaches to motivate cognitively impaired workers through in-situ instructions [10, 9]. However, an in-depth analysis of the effects of in-situ instructions on impaired workers has not been conducted yet. This paper aims to close this gap with the following three main contributions: (1) we introduce an assistive system that can automatically detect a worker's actions at the workplace (2) Through a comprehensive study with impaired workers, we compare the effects of our in-situ projection-based prototype against state-of-the art pictorial instructions (3) We discuss implications in-situ instructions for planning sheltered work assembly workplaces and better integrating impaired workers into the working life.

ANALYZING THE STATE OF THE ART

To analyze the state-of-the-art of assembling products in a sheltered work organization, we analyzed a factory of our associate sheltered work organization with 72 impaired employees and 14 supervisors that are supporting the impaired employees. The supervisors consist of one social education supervisor and 13 technical supervisors. The impaired employees are workers with either cognitive disabilities (e.g. workers with down syndrome) or workers with mental disabilities (e.g. workers with tourette syndrome or burnout syndrome). The analyzed factory is producing cutting products (e.g. scissors, pliers, or pincers) and further has a carpentry for producing tables and benches.

The analyzed factory offers 93 assembly workplaces. The number of assembly steps that needed to be preformed at each workplace were counted. This counting included steps like picking up and placing of a part as well as a tools usage as a working step. According to this method, the workplaces analyzed consist of 1 to 25 working steps per product. Our analysis revealed an average amount of 5.25 ($SD = 4.05$) working steps per workplace.

To support workers during their working tasks, the sheltered work organization offers pictorial instructions that are mounted directly over the boxes which hold the parts to be assembled (see Figure 2). The instructions show the assembled product in the intermediate state after the part in the box is assembled. The workers can control their assembled product using the picture, e.g. if the last part was assembled correctly or where to assemble the next part. In case the workers do not understand the pictorial instructions, there is always a supervisor around who can provide help with assembling the next part.

Overall, the factory is designed to split each product into small sub tasks, which the impaired workers can perform only with the help of the pictorial instructions. This segmentation of working tasks leads to a higher level of satisfaction of the workers because they can complete a whole task without help. Just in case they need help, they can still consult the supervisors.

Figure 2. A state-of-the-art assembly workplace that is used in the analyzed sheltered work organization. Pictorial instructions above the boxes which hold the parts to assemble show how the assembly has to be performed. Workers can compare their assembled product with the depicted instruction.

RELATED WORK

Augmenting reality with information goes back to Sutherland [18]. In his prototype, he overlayed the view of participants with objects that are close and objects that appear to be far away. However, the idea of augmenting working processes with visual information has been around about only two decades. In 1993, Caudell et al. [3] suggested using head-mounted displays for displaying drilling spots and instructions. Over the years, research has defined sub-categories of Augmented Reality according to the different use cases and the ways of presenting information. For example, we refer to Spatial Augmented Reality (SAR) [14] when an object is being displayed directly onto the physical space around the user. An example for SAR is the Everywhere Displays Projector [13], where information is projected directly into the physical world with respect to the physical properties. Another sub-category is Industrial Augmented Reality (IAR), which refers to using Augmented Reality for industrial use cases. Navab [11] and Fite-Georgel [5] categorize IAR according to the different use cases: product design, commissioning, training, manufacturing, inspection and maintenance, and decommissioning.

A central aspect of IAR is presenting context aware instructions at the assembly workplace. These three competing technologies currently available for this are projected feedback, using augmented tools, and using head-mounted displays. Bannat et al. [2] used a top-mounted projector to provide in-situ feedback. Further they used an RGB-camera to detect which box the worker is picking the next part from. Their system can provide context sensitive help at the workplace according to which assembly part was picked by equipping the worker with a grasping sensor. This grasping sensor ensures that the worker actually picked up an item from the box and that the sensor did not just register the placement of his or her hand above the box. Rüther et al. [15] use projection for displaying information in sterile environments. In their study they found that using projected instructions for cleaning medical instruments is well received and leads to less errors than using paper-based instructions. In 2012, Korn et al. [9] suggested using motion and voice input for sensing and triggering events at an augmented workplace using in-situ projection. They further suggested using gamification elements in conjunction with the measured interaction to motivate workers during their work tasks. Zhou et al. [21] use in-situ projection for displaying welding spots in manual welding tasks for quality control and during a welding task. They are use a stationary projector to display the feedback to the worker. On the other hand, Echtler et al. [4] suggest a hand-held approach for displaying welding spots. Considering head-mounted displays, Zheng et al. [20] compared the position of feedback that is shown on a head-mounted display during an assembly task with non-impaired workers. They conclude that the worker's task was performed faster with a display that directly overlays reality than a peripheral display.

Pictorial instructions are used to teach persons with impairments in various situations [12]. A positive effect of pictorial instructions is that they are language independent and can be easily understood. In a study with 81 impaired workers, Korn et al. [10] compared in-situ pictorial instructions to "state of the art instructions" for assembling Lego cars. They found that pictorial in-situ instructions lead to a faster assembly, but workers were making more errors compared to the control condition. Recently, Funk et al. [6] found that contour-based in-situ instructions lead to a lower task completion time and less errors compared to in-situ video and in-situ pictorial instructions for cognitively impaired workers. In their study, they also found that more complex tasks have a negative effect on cognitively impaired workers. An overview about assistive technology for persons with cognitive disabilities is provided by Sauer et al. [17]. They conclude that through continuously offering instructions, cognitively impaired workers can work on more complex products.

Overall, previous work explored how to use IAR for workplaces and found that in-situ projected instructions are having a positive effect on cognitively impaired workers. However, it is not quantitatively explored yet to which extend in-situ projected instructions are better than state-of-the-art pictorial instructions. Therefore, we designed a system which is able to provide context sensitive in-situ instructions and is easily able to change workflows.

SYSTEM

We built an assistive system for the workplace that consists of a top-mounted Kinect depth camera for sensing interaction with the system and a top-mounted projector to provide in-situ feedback according to the working steps. The system consists of a Microsoft Kinect_v2 and an Acer K330 projector. We used a tower PC with a GeForce GT740 graphics card and an i7 quad-core processor. We firmly mounted the Kinect and the projector using aluminum profiles just as they are used in the industry. The projector and the Kinect are mounted 1.4m above the working area (see Figure 4 A)). Behind the working area there are boxes containing the spare parts (see Figure 4 B)). Further, we firmly mounted a Lego Duplo plate at the table, which defines the working area (see Figure 4 C)).

Using the Kinect-depth image, the system is able to detect two types of working steps. In the first step, the system can detect which box the worker is picking a part from (see Figure 3). The system accomplishes this by continuously checking the depth data within the previously defined areas that are placed over the boxes. The covered area is in the front of the box and is 50mm high. By considering the height of the boxes, the system can distinguish between boxes that are placed above each other. Picking up an assembly part from the box is detected when 40% of the depth data within the surveyed area changes. In the second step, the system is able to detect the correct assembly of the of the picked part when placed in the working area based on depth data. When creating the work instructions, the system saves the depth data of the correctly assembled part. The system is then able to detect correct assembly by comparing the depth data in the predefined working area to the previously stored data of a correct assembly. To eliminate

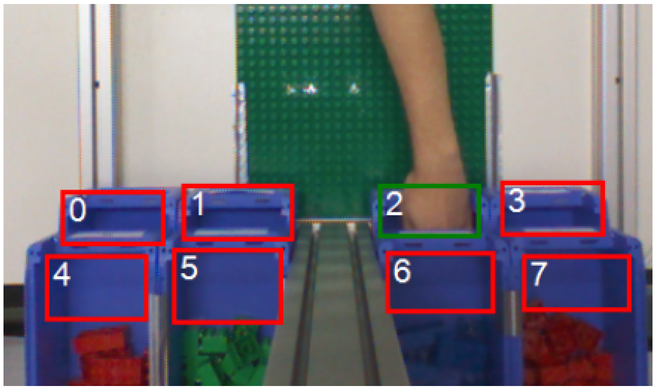

Figure 3. The pick detection of the boxes can be defined according to the workplace using the image of the top-mounted Kinect. The system can detect from which box the participant is picking a Duplo brick. Green indicates that a pick was detected, red indicates that no pick was detected.

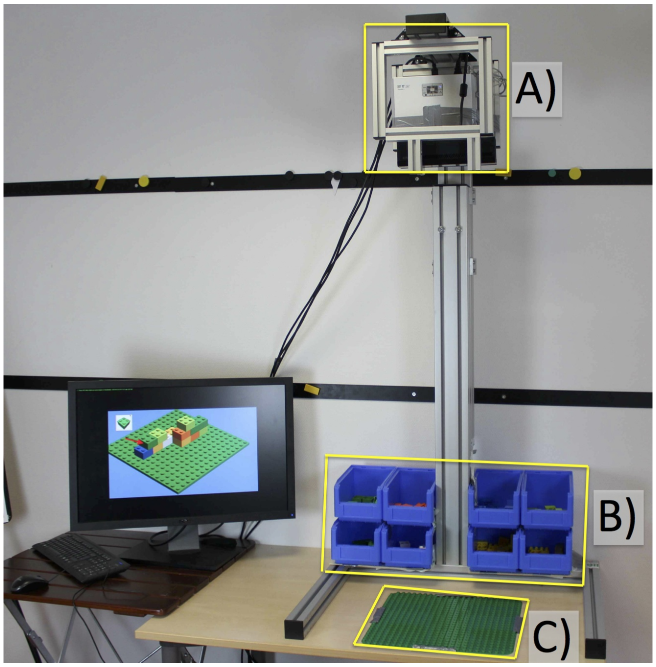

Figure 4. Our prototypical system for an assitive system providing visual in-situ instructions at the workplace. A) the top-mounted Kinect and the projector B) the boxes containing the spare parts C) the working area which is checked for correct assembly

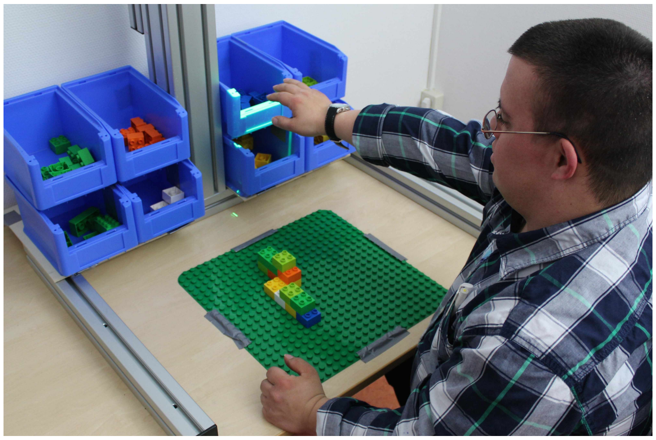

Figure 6. The system shows the worker from which box the next part has to be picked using a green light.

sensor noise, we smooth the depth image over 15 frames and calculate a mean depth value. We defined a part to be correctly assembled when 85% of the pixels in the smoothed image match the depth data of the correct state.

For indicating which box to pick parts from, the system highlights the correct box using a green light (see Figure 6). Informed by previous research [6, 7], we designed the instructions to display the contour of the parts at the position they should be placed using a green light (see Figure 1). The system advances to the next instruction when the working step was correctly preformed (i.e. when placing the hand into a box or when assembling the previously picked part correctly). Thereby, the system implements continuous context-aware feedback according to the current working step and provides an implicit quality control based on the depth data of the assembly.

Considering setting up the system, we implemented a four point calibration to unify the depth image and the projector similar to Hardy et al. [8]. Using this approach, calibration can be done in a few seconds. For teaching a workflow, the system implements a teaching by example functionality where the correct assembly of each work step has to be demonstrated once. After a work step was performed, the user has to press a button which triggers the system to save the depth data of the correctly assembled work-piece. Based on the depth-data, it can detect where the work-piece has changed and automatically calculate the shape and position of the feedback that is projected at the assembly position. Using this functionality, the time it takes to setup a workflow is approximately three times as much as just assembling the work-piece.

EVALUATION

We conducted a user study to assess the effects of in-situ instructions provided by our assistive system and compared it to state-of-the-art pictorial instructions at a workplace with impaired workers. Informed by previous work [19, 16], we chose a Lego Duplo task as an abstract assembly task that can be easily scaled up to use more working steps without introducing a different product. Furthermore, such a pick-and-place task is a good abstraction of tasks that are usually performed in sheltered work organizations, as those tasks also require picking parts and placing them at defined assembly positions. However, using a tool on the placed assembly parts is not included in this abstract assembly task.

Method

For evaluating the system, we considered a repeated measures design with two independent variables; The used instruction, and the number of bricks in the assembled construction. We measured the task completion time (TCT) and the error rate (ER) as dependent variables. To normalize the data, we divided the TCT and the ER by the number of bricks that the construction consists of to get the time per brick (TPB) and the errors per brick (EPB).

Apparatus

We considered 5 different difficulty levels with constructions consisting of a different number of bricks (see Figure 5): 3, 6, 12, 24, and 48 bricks. As placing one brick results in two working steps, i.e. picking the brick and placing it at the correct position, the levels result in 6, 12, 24, 48, and 96 working steps. The Lego Duplo constructions in their final state are depicted in Figure 5 (a)-(e).

For the in-situ instruction condition, we used the previously described system, which highlights the box to pick from and displays the contour of the picked brick at the correct assembly position. As the assembly detection requires the participant to remove his or her hand from the assembled brick, the researcher was able to advance the feedback manually using a wireless presenter in case the participant is occluding the assembled part by leaving the hand above the assembled brick.

As a state-of-the-art control condition, we used pictorial instructions to show the next part and assembly position to the worker. We used a 28” screen next to the assembly area see Figure 4. The pictorial instructions provide three main types of information. First, the type of brick to pick, depicted by a icon in the upper left corner (also see Figures 5 (a)-(e)). Second, a picture showing the work-piece in the correct state after the current brick was assembled at the correct position. Third, a red arrow directly highlighting the position of the last placed brick. This type of information enables the participant to see the placement position of the current brick immediately. This is useful because finding the correct position of the brick could be cumbersome, especially with an increasing number of bricks. The instructions were created using the Lego Digital Designer[3]. The pictorial instructions were proceeded by the researcher using a wireless controller after the participant placed the brick at a position. This enabled the participant to fully focus on the assembly task.

Procedure

After explaining the purpose of the study, we asked the participant to sit down in front of the work station. Depending on the condition to be conducted, we either explained how a pictorial instruction is understood or how the in-situ projection shows the part to pick and where to assemble it. We

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[3] Lego Digital Designer - `http://ldd.lego.com/en-us` (last access 05-07-2015)

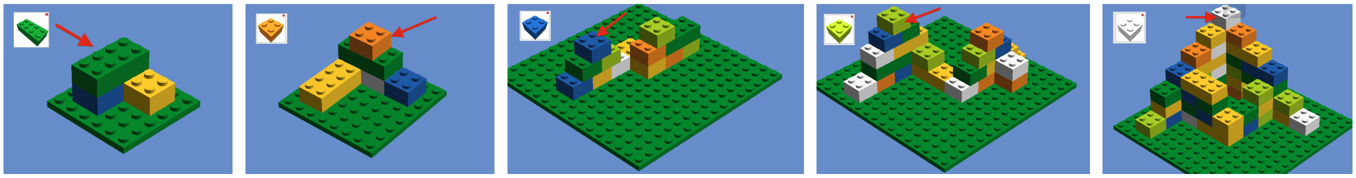
(a) (b) (c) (d) (e)

Figure 5. The constructions used in the study. We considered five different complexity levels: (a) 3 bricks, (b) 6 bricks, (c) 12 bricks, (d) 24 bricks, and (e) 48 bricks. The images depict the final step of the pictorial instructions.

instructed the participants to primarily focus on assembling the constructions correctly and only secondarily focus on the assembly time. During the experiment, the TCT was taken and the number of errors was counted independently by two researchers. The researchers started the measuring of the TCT upon showing the first instruction and stopped the measuring when the construction was finished. In case of inconsistency between the two counted error numbers, the assembled building was analyzed for errors. The researchers distinguished between picking errors and placement errors. A picking error is counted when the participant was picking a brick from a wrong box, and a placement error is counted when a brick is placed at a wrong position in the assembly area considering the relative position to the other bricks. In case a placement error effected the possibility to finish the construction correctly and not to influence further working steps, the researchers paused the experiment and the measuring of the TCT to get the assembly back into a correct state. In the pictorial instruction condition, the absolute position on the plate was not checked for correctness. The researchers instructed the participants to begin with the first brick in the middle of the plate and not determine the exact position of the brick on the plate in the pictorial instruction. This procedure was repeated for all 5 constructions for both the pictorial and in-situ conditions respectively. After each condition, subjective feedback from the participant was collected by asking for their opinion about the feedback of the respective conditions. The order of the constructions and the conditions were counterbalanced according to the Balanced Latin Square over the 15 participants. We ensured that each Performance Index group had the same 5 orders of the constructions.

Participants

Our partnering sheltered work organization uses a Performance Index to assess the performance of their workers and to be able to assign them to tasks that they are capable of conducting. The Performance Index (PI) is measured in percentages and indicates to what extent an impaired worker is capable of performing a task compared to a worker without disabilities. The PI is determined subjectively by the supervisor of the impaired worker who works with the impaired worker every day. We considered three PI groups: PI of $5\% - 10\%$, PI of $15\% - 35\%$, and a PI over 40%. We chose the participants for the study in a way that 5 participants belonging to each PI group took part in the study, which results in a total number of 15 participants.

Accordingly, we recruited 15 participants (4 female, 11 male) for the study. The participants were aged from 20 to 55 years ($M = 40.1$, $SD = 10.33$). All participants were employees of a sheltered work organization and were workers with a cognitive disability. None of the participants were familiar with the Duplo constructions that were assembled in the study. However, all participants had experiences playing with Duplo bricks before. For each participant, the study took approximately 60 minutes.

Results

We statistically compared the TPB and the EPB between the in-situ instructions and the pictorial instructions using a one-way repeated measures ANOVA. The assumption of homogeneity of variance had not been violated ($p > .05$) for the TPB and the EPB.

Considering the TPB for the task consisting of 3 bricks, the in-situ instructions were faster ($M = 6.74$ sec, $SD = 1.72$ sec) than the pictorial instructions ($M = 9.98$ sec, $SD = 3.26$ sec). The analysis revealed a significant difference between the instructions ($F(1, 14) = 18.088$, $p < .001$). The effect size estimate shows a large effect ($\eta^2 = .564$). For the task consisting of 6 bricks, the in-situ instructions were faster ($M = 7.18$ sec, $SD = 2.95$ sec) than the pictorial instructions ($M = 9.49$ sec, $SD = 4.41$ sec). The ANOVA revealed a significant difference between the instructions ($F(1, 14) = 5.698$, $p = .032$). The effect size estimate shows a large effect ($\eta^2 = .289$). When analyzing the 12-brick task, again the in-situ instructions were faster ($M = 7.20$ sec, $SD = 2.93$ sec) than the pictorial instructions ($M = 11.61$ sec, $SD = 5.01$ sec). The statistical comparison revealed a significant difference between the instructions ($F(1, 14) = 22.567$, $p < .001$). The effect size estimate shows a large effect ($\eta^2 = .617$). For the task consisting of 24 bricks, the in-situ instructions were faster ($M = 8.03$ sec, $SD = 3.09$ sec) than the pictorial instructions ($M = 11.53$ sec, $SD = 5.05$ sec). The ANOVA revealed a significant difference between the instructions ($F(1, 14) = 12.981$, $p = .003$). The effect size estimate shows a large effect ($\eta^2 = .481$). Finally, when analyzing the task consisting of 48 bricks, the in-situ projected instructions were faster ($M = 7.40$ sec, $SD = 2.00$ sec) than the pictorial instructions ($M = 14.21$ sec, $SD = 5.04$ sec). The ANOVA revealed a significant difference between the instructions ($F(1, 14) = 50.027$, $p < .001$). The effect size estimate shows a large effect ($\eta^2 = .781$). Figure 7 shows an overview of the results.

Considering the EPB for the task consisting of 3 bricks, the in-situ instructions were leading to less errors ($M = 0.02$, $SD = 0.08$) than the pictorial instructions ($M = .08$, $SD = .23$).

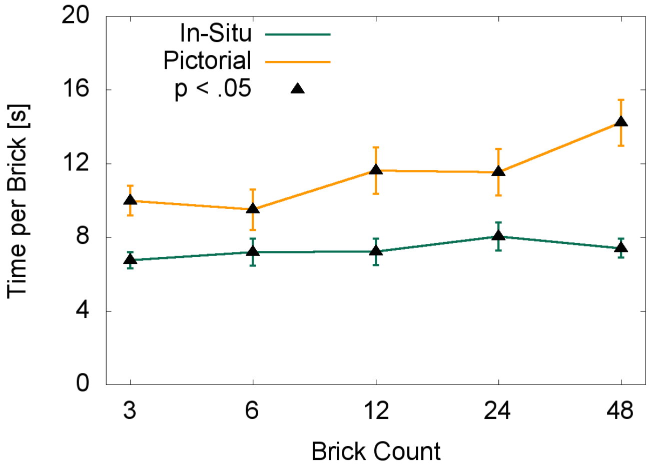

Figure 7. Overview showing the time needed to pick and assemble a brick dependent on the complexity of the product to assemble. Error bars depict the standard error. A triangle indicates a significant difference between the conditions.

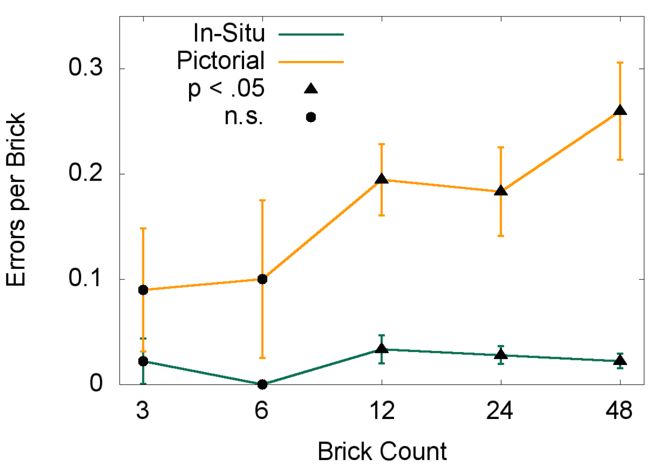

Figure 8. Overview showing the errors made dependent on the complexity of the product to assemble. Error bars depict the standard error. A triangle indicates a significant difference between the conditions.

The analysis did not reveal a significant difference between the instructions ($F(1,14) = 1.014$, $p = n.s.$). For the task consisting of 6 bricks, the in-situ instructions did not lead to any error. The pictorial instructions lead to a few errors ($M = 0.10$, $SD = 0.30$). The ANOVA did not reveal a significant difference between the instructions ($F(1,14) = 1.669$, $p = n.s.$). When statistically analyzing the EPB of the 12-brick task, the in-situ instructions ($M = 0.03$, $SD = 0.05$) lead to less errors than the pictorial instructions ($M = 0.19$, $SD = 0.13$). The statistical comparison revealed a significant difference between the instructions ($F(1,14) = 27.605$, $p < .001$). The effect size estimate shows a large effect ($\eta^2 = .664$). For the task consisting of 24 bricks, the EPB of the in-situ instructions were lower ($M = .02$, $SD = .03$) than the EPB of the pictorial instructions ($M = 0.18$ sec, $SD = .16$). The ANOVA revealed a significant difference between the instructions ($F(1,14) = 15.321$, $p = .002$). The effect size estimate shows a large effect ($\eta^2 = .523$). Finally, when analyzing the task consisting of 48 bricks, the projected instructions lead to less errors ($M = .02$, $SD = .02$) than the pictorial instructions ($M = .26$ sec, $SD = .18$ sec). The ANOVA revealed a significant difference between the instructions ($F(1,14) = 30.455$, $p < .001$). The effect size estimate shows a large effect ($\eta^2 = .685$). Figure 8 shows a graphical representation of the results.

We further analyzed the effect of number of working steps on TPB and EPB for both pictorial and in-situ instructions using a repeated measures ANOVA. Mauchly's test showed that the sphericity assumption was not violated for TPB and EPB.

Regarding the pictorial instructions, the analysis revealed a significant difference in TPB between the different step sizes ($F(4,56) = 7.144$, $p < .001$). Pairwise comparisons revealed that the difference in TPB between the 48 brick and 12 brick task, 48 brick and 6 brick task, and 48 brick and 3 brick task are significantly different (all $p < .05$). Considering the EPB, between the different step sizes using pictorial instructions, the analysis did not reveal a significant difference ($F(4,56) = 2.291$, $p = n.s.$). Considering the in-situ instructions, the analysis did not reveal a significant difference in TPB between the different step sizes ($F(4,56) = 1.264$, $p = n.s.$). Also for the EPB, the ANOVA could not show a significant difference between the step sizes ($F(4,56) = 1.012$, $p = n.s.$).

During the study, the participants commented on the different types of instructions. Regarding the in-situ instruction, participants liked that *"the system is showing the next box"* (P7, P11) and that *"[it] exactly shows where to put the next brick"* (P3, P7, P14). A participant referred to the system as *"magic light that helps performing the task"* (P2). Considering the pictorial instructions, the participants liked that *"the instructions are shown on a computer rather than on a printout"* (P7). However, a participant stated that he was *"having problems to find the correct positions as other bricks in the image are confusing"* (P6).

The supervisors of the sheltered work organization reported that in the days after the study, the participants were asking them if they can work at the *"workplace with the lights again"* and that it was fun for them and they enjoyed working with our system. They even asked when they will be able to perform their regular tasks with the help of *"the lights."*

DISCUSSION

The results of the user study suggest that in-situ instructions have several advantages over the state-of-the-art pictorial instructions. First, the time per brick is up to 1.6 times lower using the in-situ instructions. The difference between the in-situ and pictorial instructions is statistically significant for all used complexity levels that were used in the study. Second, the errors per brick is up to 3 times lower using the in-situ instructions compared to pictorial instructions. This difference is statistically significant for the constructions consisting of 12, 24, and 48 bricks. When considering the TPB and EPB, the values across the different complexity levels are rather constant for the in-situ instructions. For the pictorial instructions, the difference between the complexity levels regarding the TPB is even significantly different. The qualitative feedback also indicates that the participants preferred the in-situ instructions over the pictorial instructions as the in-situ instructions were always showing the position. Considering the pictorial instructions, the participants found that with increasing complexity it becomes harder to find the correct assembly position albeit there was a red arrow indicating the position. We believe that this is because a more complex structure requires more cognitive processing and that the assembly position is only highlighted in the instruction and not in the assembly position itself.

Implications

The aforementioned user study revealed two implications considering the design of assembly tasks for cognitively impaired workers in sheltered work organizations. First, in-situ projected instructions should be used to instruct workers rather than pictorial instructions. When using in-situ instructions instead of pictorial instructions, impaired workers could assemble faster and with fewer errors. Second, impaired workers could be used to assemble more complex products with a steady error rate and a steady assembly time, even with increasing complexity of the working task. This could further integrate impaired workers into the working life and could lead to a higher satisfaction.

Limitations

It should be mentioned that the proposed system has certain limitations. Some of the impaired workers in the user study were leaving their hand in the working area covering the previously assembled brick which caused the system not to trigger automatically. Therefore we were using a wireless presenter to advance the feedback manually in case the workers occluded the assembled part and retained covering the bricks. We also discovered that the Kinect_v2 sensor needs to run warm first before it can accurately detect correct assembly. When teaching the reference values with a Kinect that was recently started, the data became invalid after 20 minutes. Our observations suggest starting the Kinect 45 minutes before using it for assembly detection.

Public Exhibition

To show our assistive system to a broader audience, we exhibited our system at the trade fair for vocational rehabilitation and exhibition of workshops for persons with disabilities[4] in Nürnberg, Germany. During the four days of the fair, over 400 impaired persons were able to try our assistance system. We mounted our prototype on a height-adjustable table, to enable persons using a wheelchair to use our system, too. As a demo scenario, we considered assembling a Lego Duplo wall consisting of 9 different bricks resulting in 18 working steps. We received a positive feedback throughout the demo from both impaired persons trying our system as well as supervisors working for sheltered work organizations. Visitors stated that the system was *"easy to learn and use"*. Another visitor liked that he *"just needs to focus on one thing to have a positive achievement."*

CONCLUSION

In this paper, we presented the implementation and design of an assistive system for the manual workplace that provides in-situ instructions for performing assembly tasks. Through a user study with 15 cognitively impaired workers, we found that in-situ instructions lead to faster assembly times and to less errors compared to state-of-the-art pictorial instructions. This effect is statistically significant for tasks consisting of 3, 6, 12, 24 and 48 assembled parts when considering the assembly time and for tasks consisting of 12, 24, and 48 assembled parts when considering the number of errors. These results might have a great impact on how tasks are divided into workplaces at sheltered work organizations. Especially as using an assistive system with in-situ projection could empower cognitively impaired workers to work on more complex tasks and thereby fostering inclusion. We believe that systems similar to the proposed prototype will become very relevant in sheltered work organizations soon, as cost, availability, and quality of the used components will improve.

In future research, we want to explore the effects of an assistive system offering in-situ instructions to cognitively impaired workers in a long-term study with a runtime of several months. We are particularly interested if the positive effects of in-situ instructions can be retained over a longer period of time or if the measured effect decreases over time. Further we want to assess potential effects on the cognitive load of the workers and explore potential effects on other areas of the worker's life, for example assisted living.

ACKNOWLEDGMENTS

This work is funded by the German Federal Ministry for Economic Affairs and Energy in the project motionEAP, grant no. 01MT12021E. We thank the Gemeinnützige Werkstätten und Wohnstätten GmbH for supporting us. We especially would like to thank Frank Raschhofer for perfectly organizing the study. Further, we thank Thomas Kosch and Michael Matheis for helping with the implementation and Chloe Eghtebas for proof reading our paper.

REFERENCES

1. United nations: United nations convention on the rights of persons with disabilities. `http://www.un.org/disabilities/convention/conventionfull.shtml`, 2008. [Online; accessed 02-May-2015].
2. Bannat, A., Wallhoff, F., Rigoll, G., Friesdorf, F., Bubb, H., Stork, S., Müller, H., Schubö, A., Wiesbeck, M., and Zäh, M. 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* (2008).
3. Caudell, T. P., and Mizell, D. W. Augmented reality: An application of heads-up display technology to manual manufacturing processes. In *System Sciences, 1992. Proceedings of the Twenty-Fifth Hawaii International Conference on*, vol. 2, IEEE (1992), 659–669.

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[4] `https://www.werkstaettenmesse.de` (last access 05-07-2015)

4. Echtler, F., Sturm, F., Kindermann, K., Klinker, G., Stilla, J., Trilk, J., and Najafi, H. The intelligent welding gun: Augmented reality for experimental vehicle construction. In *Virtual and augmented reality applications in manufacturing*. Springer, 2004, 333–360.
5. Fite-Georgel, P. Is there a reality in industrial augmented reality? In *Mixed and Augmented Reality (ISMAR), 2011 10th IEEE International Symposium on*, IEEE (2011), 201–210.
6. Funk, M., Bächler, A., Bächler, L., Korn, O., Krieger, C., Heidenreich, T., and Schmidt, A. 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 (2015).
7. Funk, M., and Schmidt, A. Cognitive assistance in the workplace. *Pervasive Computing, IEEE 14*, 3 (2015), 53–55.
8. Hardy, J., and Alexander, J. Toolkit support for interactive projected displays. In *Proceedings of the 11th International Conference on Mobile and Ubiquitous Multimedia*, ACM (2012), 42.
9. Korn, O., Schmidt, A., and Hörz, T. Assistive systems in production environments: exploring motion recognition and gamification. In *Proceedings of the 5th International Conference on PErvasive Technologies Related to Assistive Environments*, ACM (2012).
10. Korn, O., Schmidt, A., and Hörz, T. The potentials of in-situ-projection for augmented workplaces in production: a study with impaired persons. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, ACM (2013), 979–984.
11. Navab, N. Developing killer apps for industrial augmented reality. *Computer Graphics and Applications, IEEE 24*, 3 (2004), 16–20.
12. Pierce, K. L., and Schreibman, L. Teaching daily living skills to children with autism in unsupervised settings through pictorial self-management. *Journal of applied behavior analysis 27*, 3 (1994), 471–481.
13. Pinhanez, C. The everywhere displays projector: A device to create ubiquitous graphical interfaces. In *Ubicomp 2001: Ubiquitous Computing*, Springer (2001), 315–331.
14. Raskar, R., Welch, G., and Fuchs, H. Spatially augmented reality. In *First IEEE Workshop on Augmented Reality (IWAR'98)*, Citeseer (1998), 11–20.
15. Rüther, S., Hermann, T., Mracek, M., Kopp, S., and Steil, J. An assistance system for guiding workers in central sterilization supply departments. In *Proceedings of the 6th International Conference on PErvasive Technologies Related to Assistive Environments*, ACM (2013), 3.
16. Sakata, N., Kurata, T., and Kuzuoka, H. Visual assist with a laser pointer and wearable display for remote collaboration. In *Proceedings of 2nd international conference on Collaboration Technologies* (2006).
17. Sauer, A. L., Parks, A., and Heyn, P. C. Assistive technology effects on the employment outcomes for people with cognitive disabilities: a systematic review. *Disability & Rehabilitation: Assistive Technology 5*, 6 (2010), 377–391.
18. Sutherland, I. E. A head-mounted three dimensional display. In *Proceedings of the December 9-11, 1968, fall joint computer conference, part I*, ACM (1968), 757–764.
19. Tang, A., Owen, C., Biocca, F., and Mou, W. Comparative effectiveness of augmented reality in object assembly. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM (2003), 73–80.
20. Zheng, X. S., Foucault, C., Matos da Silva, P., Dasari, S., Yang, T., and Goose, S. 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*, ACM (2015), 2125–2134.
21. Zhou, J., Lee, I., Thomas, B., Menassa, R., Farrant, A., and Sansome, A. Applying spatial augmented reality to facilitate in-situ support for automotive spot welding inspection. In *Proceedings of the 10th International Conference on Virtual Reality Continuum and Its Applications in Industry*, ACM (2011), 195–200.