Mobile In-Situ Pick-by-Vision: Order Picking Support using a Projector Helmet

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ABSTRACT

Order picking is one of the most complex and error-prone tasks that can be found in the industry. To support the workers, many order picking instruction systems have been proposed. A large number of systems focus on equipping the user with head-mounted displays or equipping the environment with projectors to support the workers. However combining the user-worn design dimension with in-situ projection has not been investigated in the area of order picking yet. With this paper, we aim to close this gap by introducing HelmetPickAR: a body-worn helmet using in-situ projection for supporting order picking. Through a user study with 16 participants we compare HelmetPickAR against a state-of-the-art Pick-by-Paper approach. The results reveal that HelmetPickAR leads to significantly less cognitive effort for the worker during order picking tasks. While no difference was found in errors and picking time, the placing time increases.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces

Author Keywords

Order Picking; Assistive Systems; In-Situ Projection; Augmented Reality

INTRODUCTION

Order picking, i.e. finding and picking stored items in a warehouse, is one of the most complex and error-prone tasks in the process of manufacturing a product. In the last years, fully-automated order picking systems (e.g. Amazon Robotics[1]) have been proposed. However, for small companies an investment in an automated order picking system is unprofitable. Thus, workers are used to pick the items from the warehouses manually. As more and more companies are organizing their material supply in a way that storage costs are minimized, the cognitive requirements for the picking process are increasing and picking errors are cumbersome to correct. Therefore, systems to cognitively support workers during order picking tasks have been proposed. The traditional approach to cognitively support workers who are working in order picking (so-called pickers) is using a paper picking list. With technology getting more and more advanced, the order picking instruction systems are becoming increasingly technology-dependent. A renown order picking instruction system is the Pick-by-Light system e.g. by KBS[2]. Another well-known order picking support system is the Pick-by-Voice system, which is a body-worn system that enables the picker to have both hands free for the picking tasks. The picking instructions are read to the picker who is wearing a headset. E.g. one of the Pick-by-Voice solutions is Topsystem Pick-by-Voice[3].

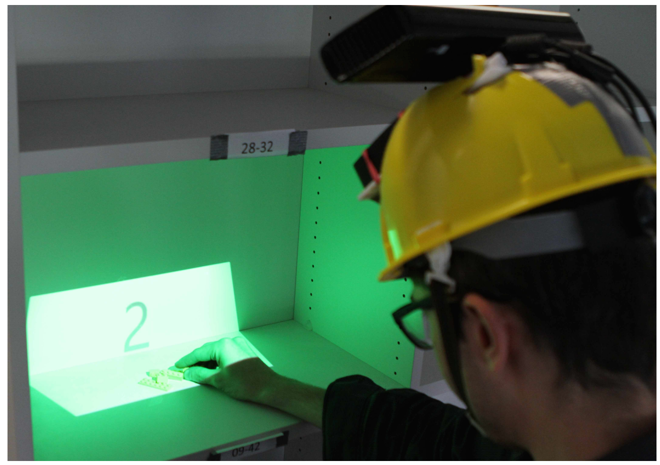

Figure 1. A user is interacting with the order picking helmet. The helmet highlights the compartments storing the items to pick and directly projects the amount of items to pick into the environment.

In this paper, we are combining the hands-free character of Pick-by-Voice with the spatially aligned visual feedback of the Pick-by-Light system by introducing an in-situ projection-based Pick-by-Vision system. The contribution of this paper is two-fold: (1) We introduce HelmetPickAR, a body-worn camera-projector helmet for providing in-situ instructions during order picking tasks and (2) evaluate the HelmetPickAR system by comparing it to a Pick-by-Paper baseline.

[1]Amazon Robotics - https://www.amazonrobotics.com - last access 04-04-2016

[2]http://www.kbs-gmbh.de/en/paperless-picking/pick-by-light - last access 04-04-2016

[3]http://www.topsystem.de/pick_by_voice.html - last access 04-04-2016

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RELATED WORK

For related approaches in order picking, research is mostly using two types of technology: camera-projection systems and head-mounted displays (HMDs). Considering the Head-mounted Displays for supporting pickers during order picking tasks, Schwerdtfeger et al. [11] and Reif et al. [9] propose using a HMD-based technique similar to the Attention funnel proposed by Biocca et al. [2]. Thereby, the picker is guided by a visual cue to the next compartment to pick from. Schwerdtfeger et al. [10] thought about using projectors instead of HMDs for Augmented Reality in 2008. They argue that a head-worn or a shoulder-worn projector might be beneficial as the system will be mobile and occlusion-free.

Over the last years many different projector-based systems have been proposed. Funk et al. [4] introduced a mobile cart that is carrying three camera-projector pairs. In a study, they found that the camera-projector cart outperforms traditional order picking systems. A system that outperforms the traditional order picking systems to a similar extent is the grid visualization suggested by Guo et al. [5]. They are using a grid visualization proposed by Weaver et al. [12] and use a smart picking algorithm that enables the picker to pick from multiple compartments at the same time. The schematic grid visualization is presented on both cart-mounted display and an HMD-based approach. Their results suggested that their technique is better than the paper baseline. Research also focused on how to present projected instructions for order picking. E.g. Bächler et al. [1] are evaluating appropriate pictograms for using in-situ projected order picking support systems in sheltered work organizations. On the other hand technologies to automatically detect picked items were proposed: e.g. Li et al. [7] are using a Kinect_v1 that is mounted over a picking bin to detect the content of a picking bin as a quality control for order picking tasks. Löchtefeld et al. [8] are using a hand-held camera-projector pair to identify and categorize products at a shopping scenario. Their Shelftorchlight prototype uses an RGB object recognition to identify products and a small projector to give feedback. Another projector-based but stationary approach is Searchlight by Butz et al. [3]. They are using a ceiling-mounted projector to highlight books in shelves.

Overall, many HMD and projection-based systems have been proposed. Although proposed by Schwerdtfeger et al. [10], a body-worn projector-based system was not yet investigated for order picking tasks. In this paper, we aim to resume their idea and build a fully functional prototype of a projector helmet that is used for performing order picking tasks.

HELMETPICKAR: AN ORDER PICKING HELMET

Inspired by related work [10], we designed a system combining in-situ projection and user-worn technology by equipping a helmet with a camera-projector pair. For building the prototype, we use a standard building-site helmet and cut out the top (see Figure 2) to insert a plastic plate carrying a projector and a Kinect_v1. As a projector, we are using a Philips Picopix PPX3610 projector with 100 ANSI Lumen that is connected to a laptop via HDMI. Further, the helmet is equipped with an OptiTrack marker to track the position and orientation of the user within an accuracy of millimeters. We chose to use wires

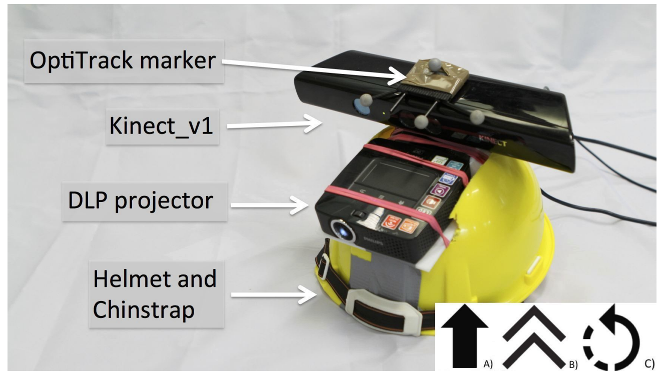

Figure 2. The HelmetPickAR order picking helmet and the arrows that can be displayed to navigate the participant.

connecting the helmet to the laptop as we need to transfer the depth image of the Kinect_v1, the video feed of the projector, and power both Kinect_v1 and projector using an external power supply. The laptop is responsible for calculating visual feedback that is shown to the user. The algorithm calculates an in-situ feedback according to the current picking tasks by using the position and orientation of the user.

When the worker approaches a shelf, the HelmetPickAR system first determines the user's position and calculates the shortest path towards the target compartment. The system uses an arrow visualization to communicate the direction into which the user has to walk to reach the target compartment (see Figure 2 - bottom right). The solid arrows (A) communicate the direction of the target compartment when facing a shelf. The two arrows (B) indicate when a user is too close or too far away from the shelves. The round arrow (C) tells the worker to turn around and start with the placing of the previously picked parts. When the worker is looking at the correct compartment, HelmetPickAR illuminates the compartment using a green light. Inspired by previous work [4], the number of parts to pick is displayed directly in the compartment.

EVALUATION

To evaluate the HelmetPickAR system, we conducted a user study comparing HelmetPickAR to the state-of-the-art Pick-by-Paper instruction method.

Design

We conducted a repeated measures study with the used order picking instruction system (HelmetPickAR or Pick-by-Paper) as the only independent variable. As dependent variables, we measure the task completion time, the number of errors, and the NASA-TLX [6] score. We use two different tasks for the study. Both tasks required picking from 10 different compartments. Further, they require the same walking distance to complete the task. To be able to analyze the performance for each picking step, we measure the task completion time (TCT) for both picking and placing the items separately. As errors, we counted picking from a wrong compartment, placing the picked items at a wrong target position, and picking the wrong number of items. We further collected qualitative feedback through semi-structured interviews after the study. The order of the conditions and the used tasks were counterbalanced.

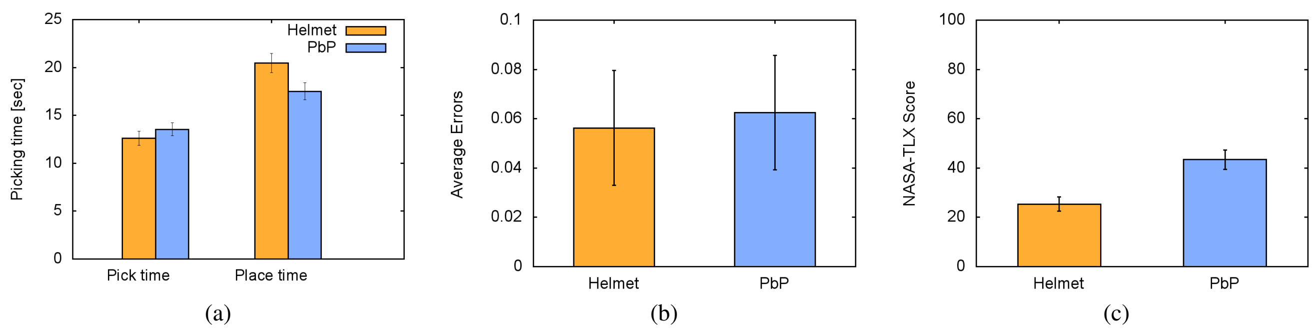

Figure 3. The results of the user study comparing the picking helmet and the Pick-by-Paper baseline: (a) the task completion time (TCT) for both picking and placing tasks, (b) the average error rate (ER) that was made during a picking task, and (c) the average cognitive load using the NASA-TLX score. The error bars depict the standard error.

Apparatus and Warehouse Layout

For evaluating our previously introduced HelmetPickAR system, we considered using the state-of-the-art Pick-by-Paper as a control condition. We created our Pick-by-Paper (PbP) method according to the PbP methods that were described in previous research e.g. [4, 5]. The PbP method consists of a paper list that is arranged using a table. Each order is described in one row in the table. The columns of the table contain the following information: ID, article number, amount to pick, source compartment, destination position, price of the item, and a free column that can be used as a checkbox.

As a warehouse, we prepared a room in our University's laboratory and put three shelves next to each other, which resulted in a 5×6 grid of compartments. Each compartment was identified by a number that was put directly at the compartment. We filled the compartments with Lego bricks in a way that each compartment holds ten bricks that have the same color and shape. To prevent the participants from crashing into the shelves with the helmet, we drew a white line that was $20\,cm$ away from the shelves. As target positions, we were using a $120\,cm \times 60\,cm$ table that was divided into 3 equally large target positions using white lines. The table with the target positions was positioned $2\,m$ away from the shelves.

Procedure

After welcoming the participant, we explained the course of the study and gave a general introduction about order picking. The participants were informed about their right to quit the study at all times and we asked them for permission to take pictures during the study. After signing a consent form, we collected the demographic information. Then, we gave an introduction to the first order picking instruction method according to the counterbalanced order of the conditions. Considering the PbP method, we did not instruct the participants to use the checkboxes but told them that they could use them to check already processed orders. Further, we did not tell the participants to take the packing list with them while processing the orders. They could also leave the list at one place, however, this would increase the TCT. Considering the HelmetPickAR condition, we first showed the participants a picture with all used symbols and explained their meaning (cf. Figure 2 bottom right). Further, we firmly mounted HelmetPickAR on the participants' heads using a chinstrap and gave them about two minutes to get used to the helmet. The participants were given two example orders to practice the current order picking instruction method. Once the participants felt confident in using the instruction method, and had no further questions, we started with the first picking task using the first instruction method. We instructed the participants that the first priority was not to make any errors and that the second priority was to process the orders fast. Further, we instructed the participants to consecutively perform each order. After performing the picking task, we asked the participants to fill a NASA-TLX questionnaire. We repeated the procedure for the remaining task and instruction method. After finishing the second task, we asked the participants to rank the instruction methods according to their subjective preference. Finally, we collected additional qualitative feedback through semi-structured interviews.

Participants

For the study, we recruited 16 participants (6 female, 10 male) via our university's mailing list. The participants were aged from 19 to 37 years ($M = 23.8$, $SD = 6.34$). Thirteen of the participants were students with various majors and three were employed in the industry. None of the participants were familiar with the picking tasks or order picking in general. All participants were using HelmetPickAR for the first time. The study took approximately $40\,min$ per participant. The participants were compensated with candies for their participation.

Results

We statistically analyzed the TCT divided into picking time and placing time, the number of errors (ER), and the NASA-TLX score between the helmet and the PbP using a one-way repeated measures ANOVA.

First, we analyzed the picking time (TCT) between the two order picking instruction systems, see Figure 3a. The participants needed 12.6 seconds ($SD = 2.96\,sec$) to perform a pick using HelmetPickAR and 13.53 seconds ($SD = 2.7\,sec$) using the PbP instruction. The one-way repeated measures ANOVA did not reveal a significant difference for the picking time, $F_{1,15} = 1.703$, $p > .05$. Considering the time that a participant needed to place the picked order at a target position, the participants needed 20.45 seconds ($SD = 4.03\,sec$) using HelmetPickAR and 17.51 seconds ($SD = 3.62\,sec$) using the paper baseline. A one-way repeated measures ANOVA revealed a significant difference between the two instruction systems considering placing time, $F_{1,15} = 8.183$, $p = .012$.

Regarding the ER the participants made using both instruction systems (see Figure 3b), the participants made on average .056 errors per order ($SD = .096$ errors per order) using HelmetPickAR and .063 errors per order ($SD = .096$ errors per order) using the PbP instruction. The one-way repeated measures ANOVA did not reveal a significant difference for the number of errors, $F_{1,15} = 0.028$, $p > .05$.

Considering the perceived cognitive load using both systems according to the NASA-TLX questionnaire (see Figure 3c), the participants rated HelmetPickAR with an average score of 25.37 ($SD = 11.25$) as less cognitively demanding compared to the PbP instruction with an average score of 43.38 ($SD = 15.66$). The one-way repeated measures ANOVA revealed a significant difference between the two order picking instruction systems considering the NASA-TLX score, $F_{1,15} = 17.060$, $p < .001$. For the subjective ranking after finishing both conditions, 12 (75%) participants preferred HelmetPickAR and 4 (25%) participants preferred PbP.

In the interviews the participants stated that they *"enjoyed being guided by the order picking helmet, because [they] did not have to search for the correct compartment and just follow the arrows."* (P3, P4). On the other hand participants thought that using HelmetPickAR is *"just following instructions blindly without having to put in cognitive effort."* (P12). They further thought that performing order picking tasks *"[they] felt like robots."* (P7, P12, P15). However, in general the participants liked that *"the head-mounted projection is always visible and in the line of sight."* (P3). Considering the paper baseline, a participant stated that *"carrying a paper picking list interferes with the picking task."* (P1).

DISCUSSION & CONCLUSION

In this paper, we presented HelmetPickAR, a helmet for cognitively supporting workers during order picking tasks using body-worn in-situ projection. Through a user study with 16 participants we evaluated HelmetPickAR against the state-of-the-art Pick-by-Paper approach. We found that there is no significant difference between HelmetPickAR and PbP in errors made and picking time, however PbP is significantly faster than HelmetPickAR considering placing time. We believe that this is due to the simple design of the target positions, which only consisted of three positions. The results of the study indicate that using an in-situ order picking support system is only beneficial when having more complexity in design of the target positions. Therefore, a more complex target position design might yield different results. Lastly, we found that the perceived cognitive load is significantly lower using HelmetPickAR compared to the PbP approach. Overall participants liked the experience of having an augmented view of the world without having to wear HMDs.

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