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Augmented reality as a means of conveying picking information in kit preparation for mixed-model assembly

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ABSTRACT

Kitting is a materials feeding principle that is increasingly common in mixed-model assembly. Currently, there is no consensus within industry regarding how picking information should best be conveyed to support kit preparation and research on the topic is scarce. The purpose of this paper is to determine whether information conveyance through augmented reality can be used to support time-efficient kit preparation, considering the two commonly applied approaches of single-kit preparation and batch preparation. The paper presents a novel application of augmented reality and tests it in a realistic laboratory experiment. As a basis for comparison, a traditional printed paper list is also tested. In the experiment, augmented reality is competitive both in terms of time-efficiency and picking accuracy, both for single kit and batch preparation, which indicates that augmented reality can constitute a viable option for conveying picking information in kit preparation. Especially for the batch preparation, where more information needs to be displayed, the augmented reality application is associated with considerably better performance than the paper list. The paper suggests that future research efforts should include studies on augmented reality applied in an actual industrial setting over a longer period.

1. Introduction

In mixed-model assembly, there is often a multitude of different part numbers that need to be handled within the assembly plant and the feeding of parts to the assembly is critical. The materials feeding principle of kitting is increasingly common and has also received increasing attention in the research literature (Kilic & Durmusoglu, 2015). With kitting, parts are sorted into kits before being fed to the assembly stations, so that each kit contains parts for a specific assembly object (Bozer & McGinnis, 1992). This is closely linked to the concept of set parts supply (SPS), as described by Jainury, Ramli, Ab Rahman, and Omar (2014). Within mixed-model assembly, the contents of the kits generally differ, which means that during kit preparation, reliable information must be available of which contents each kit should have. Kit preparation is generally performed by manual labour, and the conveyance of picking information should be able to support performance of the picker in the areas of both efficiency (Hanson, Medbo, & Johansson, 2015) and picking accuracy (Brynzér & Johansson, 1995; Fager, Johansson, & Medbo, 2014; Hua & Johnson, 2010). There are numerous means of conveying picking information, such as traditional printed paper lists, pick-by-voice systems, and pick-by-light systems (Battini, Calzavara, Persona, & Sgarbossa, 2015; Brynzér & Johansson, 1995; Reif, Günthner, Schwerdtfeger, & Klinker, 2010). Currently, there is no consensus within industry regarding how picking information should be conveyed in kit preparation and research on the topic is scarce.

In warehouse order picking, it has been indicated that the use of augmented reality (AR) for conveying picking information can support both time efficiency and picking accuracy (Reif et al., 2010). However, while similar to warehouse order picking in many respects, kit preparation differs in that it normally takes place within a compact picking area, where the walking distances of the picker are relatively short and picking therefore occurs with a higher frequency (Hanson et al., 2015). Therefore, results from warehouse order picking are not directly transferrable to kit preparation. Moreover, kit preparation occurs in two variants: single-kit preparation, where kits are prepared one at a time, and batch preparation, where several kits are prepared together, during the same kit preparation cycle (Hanson et al., 2015). As both these variants are commonly occurring within industry, and display different characteristics, it is of interest to study how AR could support kit preparation in each of them. The current paper has the purpose of determining whether information conveyance through AR can be used to support time-efficient kit preparation, considering both single-kit preparation and batch preparation. In line with Azuma (1997) and Reif et al. (2010), the paper defines AR as any system which combines the

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real and the virtual world using 3D registration and which is interactive in real time.

Based on a laboratory experiment, set in a realistic environment, the paper compares a novel application of AR to a traditional printed paper list for conveying picking information, with respect to the time efficiency of the kit preparation. Paper lists are still a very common means of conveying picking information within many picking applications (Grosse, Glock, Jaber, & Neumann, 2015; Guo, Wu, Shen, & Starner, 2015). In line with existing terminology (e.g. pick-by-voice, pick-by-light), the two solutions used for conveying picking information in the study are denoted "pick-by-AR" and "pick-by-paper". Based on the experiment, the paper provides quantitative evidence of how the efficiency, measured through the picking time, differs depending on which of the two picking information solutions is used and depending on whether single-kit preparation or batch preparation is applied. The paper further considers the number of picking errors that occurred during the experiment and the potential of the pick-by-AR application to support picking accuracy.

In the next section, a review of existing literature is presented. Thereafter, Section 3 presents the methodology applied in the paper. Section 4 presents the analysis and the results of the paper. In Section 5, a discussion of the results and their implications is presented, together with ideas for future research. Finally, Section 6 presents the conclusions of the paper.

2. Literature review

Much of the research that deals with picking information focuses on warehouse order picking contexts. Less has been published within the area of kit preparation.

In a warehouse order picking context, Battini et al. (2015) present a comparative analysis of different paperless systems for conveying picking information, including handheld devices with barcode and RFID scanners, pick-by-voice and pick-by-light. Schwerdtfeger, Reif, Günthner, and Klinker (2011) report on a process of exploring, evaluating, and refining solutions that use AR via a head-mounted display to support warehouse order picking. They present several findings regarding what type of AR visualisations are suitable to guide a picker. One type of visual guidance that is tested is a virtual 3D "tunnel" that appears to extend from the picker, showing the way to the picking location. Schwerdtfeger et al. (2011) find that the tunnel must be discreet in order not to obstruct the picker's view of the real world. Reif et al. (2010) present an experimental study in a warehouse order picking context and find that information conveyance via a head-mounted display and a AR solution can enable a higher time efficiency than picking information conveyance via a paper list.

Some studies have considered picking information in relation to kit preparation or other types of picking in compact picking areas. However, none of the studies has considered AR for conveying picking information. In two experiments on kit preparation in an automotive assembly setting, Hanson et al. (2015) compared the picking time associated with batch preparation to that of single-kit preparation and found that batch preparation was associated with shorter picking time. In the study, picking information was conveyed to the pickers by use of a mobile digital display. Iben, Baumann, Ruthenbeck, and Klug (2009) present an experiment, conducted in a relatively compact picking area, constituted by one picking aisle, where a head-mounted display, conveying 2D information, was compared to a printed picking list. Picking was performed to a single bin, i.e. corresponding to single-kit preparation. Comparing the performance associated with each picking information system, Iben et al. (2009) found indications of the head-mounted display being associated with both higher accuracy and higher efficiency, but the results were not statistically significant. Guo et al. (2015) present an experiment comparing four different means of conveying picking information in a compact picking area. Picking was performed to three order bins, i.e. corresponding to batch preparation. In the study, information conveyance via head-mounted displays, conveying 2D information, and cart-mounted displays enabled to more efficient and more accurate picking than pick-by-light and pick-by-paper. Neither of the head-mounted displays used in the studies of Iben et al. (2009) and Guo et al. (2015) utilised AR for conveying information and neither of the studies considered both single-kit preparation and batch preparation.

Overall, the literature review indicates that knowledge is missing regarding how pick-by-AR can support performance in kit preparation, considering both single-kit preparation and batch preparation.

3. Methodology

The paper is based on an experiment conducted in a laboratory environment, set up to simulate kit preparation in the material supply to mixed-model automotive assembly. The experiment was designed in alignment with the systematic approach proposed by Coleman and Montgomery (1993). Hence, important steps of planning the experiment included the choice of response and control variables. In line with the purpose of the paper, the time consumption was chosen as a response variable. Moreover, the number of picking errors that occurred was chosen as an additional response variable and was studied to ensure that potentially low time consumption was not associated with an increased number of errors. Two control variables were chosen: the means of information conveyance and the batching principle, i.e. whether kits were prepared one at a time or in batches. The batch size applied, i.e. the number of kits prepared in each batch, was set to four, as this was found to be a size that was both industrially relevant and practically feasible for the picker to handle.

Corresponding to the focus of the paper, the experiment included picking information conveyed by means of AR. As a basis of comparison, the experiment further included kit preparation with picking information conveyed by means of printed paper lists. While there exist several other options, including pick-by-light and pick-by-voice systems, printed paper lists are still common in industry and thus constitute a relevant alternative. Based on an experimental study of kit preparation, Fager (2016) finds that paper lists can be associated with a picking efficiency that is similar to that of pick-by-light systems and higher than that of pick-by-voice systems.

The physical set-up of the experiment – in terms of kit preparation layout, storage racks, load carriers, and components – was designed together with logistics engineers from the automotive industry, with the aim of achieving conditions as realistic as possible for the experiment. Fig. 1 displays an overview of the kit preparation area used in the experiment. As the experiment was designed to simulate kit preparation in a mixed-model assembly setting, all kits had different contents.

The pick-by-AR application used in the study was developed for the Microsoft HoloLens hardware (www.microsoft.com), which means that the information was presented to the picker via a head-mounted display. Fig. 2 shows an example of the information presented in the pick-by-AR application. For each part number that should be picked, a discreet yet clearly visible virtual 3D "tunnel" guided the picker to the right bin. When the bin was within the picker's field of view, a coloured circle and a number would appear in the bin, indicating how many components should be picked of the part number in question. This design was developed in line with the findings of Schwerdtfeger et al. (2011). During batch preparation, it was also necessary to provide the picker with information of which kit containers the components should be placed in. This was achieved by a graphic 2D representation of the four kit containers in the picking cart. The representation reflected the 2 × 2 pattern of the kit cart and was static in the picker's field of view. After having finished picking and placing a part number, the picker would use a voice confirmation to indicate that the system should move on to the next part number. To clearly signal to the picker that the confirmation had been registered, the application was designed so that the virtual tunnel and the circle highlighting the bin changed colour

Fig. 1. The kit preparation area used in the experiment, including the kit cart with four coloured boxes (as used in batch preparation).

briefly, and the circle also spun around, before the location of the next bin was indicated.

Fig. 3 shows how the picking information was conveyed via the paper picking lists: the left of the figure shows a picking list of single kit preparation and the right of the figure shows a picking list of batch preparation. The picker would read the list from top to bottom. Each row corresponds to a part number that should be picked. In the batch picking, each part number could include several components, which should then be distributed over different kit containers. The information to indicate this could then be extracted from the leftmost part of the picking list, where a representation of the 2×2 pattern of the kit cart was presented, according to the same principle as with the pick-by-AR application. The configuration of the paper lists was developed together with logistics engineers from the automotive industry, based on actual industrial practice.

Five pickers participated in the experiment: four male and one female, all in the ages between 23 and 35 years. Pickers without previous experience of kit preparation were selected to avoid previous experience biasing the comparison between pick-by-AR and pick-by-paper. To compensate for the lack of experience and minimise learning effects, the experiment was preceded by a training session, where each of the pickers practiced preparing kits in the laboratory set-up, making themselves familiar with both AR and paper lists as support.

During the experiment, kit preparation was performed by one picker at a time. In the relatively small kit preparation areas often used in industry, this has been found to be the most common approach. The picker would walk through the kit preparation area, which was u-shaped, while picking components from the storage racks and gradually filling either one or four kits, depending on whether single-kit preparation or batch preparation was applied. During picking, the kit containers were placed on a mobile cart that the picker would push through the kit preparation area. Each traversal of the picking area was denoted a picking cycle. The experiment comprised four different *configurations* of kit preparation, where each configuration constituted a combination of either pick-by-AR or pick-by-paper with either single-kit or batch preparation. Each of the pickers picked ten consecutive cycles in each of these four configurations, but went through the configurations in an individual, randomised sequence. This way, it was possible to achieve a fair comparison between the different configurations, where potential effects of differences between pickers, e.g. due to learning or fatigue, should not systematically affect the comparison. This approach adheres the experiment design guidelines suggested by Coleman and Montgomery (1993), according to which so called nuisance factors can be managed through randomisation.

All picking was video recorded by use of two different video cameras, placed so that they together captured the movements of the picker during the whole picking cycle. After the data collection, all video recordings were examined and the time to perform each picking cycle was registered and used as basis for a quantitative analysis of the picking time. In addition, the video recordings were used in the identification of picking errors. Picking errors were observed and counted in real-time, during the experiment, and later double-checked by use of the video recordings.

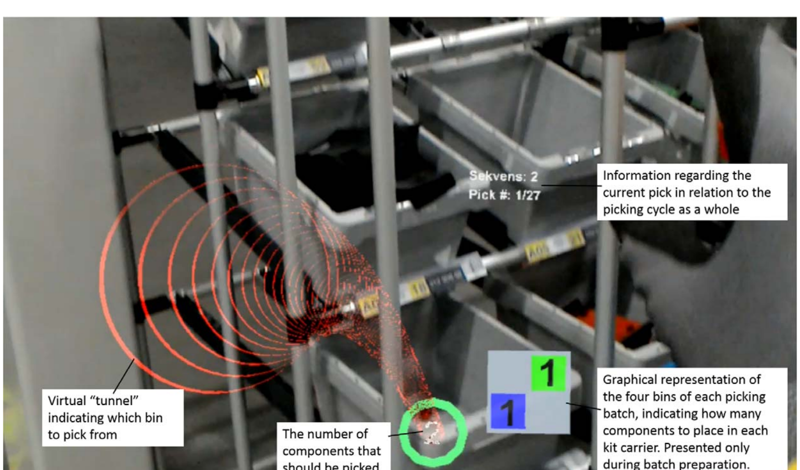

Fig. 2. An example of how information was presented to the pickers when pick-by-AR was applied during the experiment.

Loc.	Qty.	Part no.	Description	Checkbox
A01	1	153 235 00	"RED PLASTIC PLUG"	
A04	1	204 914 68	"BENT ATTACHMENT RED"	
A13	1	152 101 00	"THIN PLASTIC DOUBLE PIPE"	
A16	1	152 927 00	"DOUBLE SCREW"	
A18	1	220 557 21	"SMALL GREEN WIRE-BUNDLE	
A21	1	220 567 77	"GREEN ATTACHING CLAMP"	
A29	1	203 745 01	"BLUE ANGLED BRACKET"	
A32	1	216 259 22	"BLUE PLASTIC COVER PLATE"	
A34	1	280 211 89	"RED THIN NOZZLE"	
A45	1	819 156 92	"LIGHT ANGLED BRACKET BLUE"	
B01	1	216 810 33	"RED HOSE"	
B02	1	313 628 28	"LARGE PLASTIC COVER"	
B08	1	507 664 07	"RED LIGHTS LARGE"	
B13	1	213 106 76	"LONG PIPE"	
B15	1	218 223 26	"LARGE BEARING RED/GREEN"	

Compartment				Loc.	Qty.	Part no.	Description
1	1	1		A01	3	153 235 00	"RED PLASTIC PLUG"
			1	A03	1	153 235 02	"RED FOAM PRISM"
1	1			A04	2	204 914 68	"BENT ATTACHMENT RED"
		1	1	A08	2	204 914 69	"BENT ATTACHMENT GREEN"
	1	1	1	A11	3	152 100 00	"THIN PLASTIC PIPE"
1				A13	1	152 101 00	"THIN PLASTIC DOUBLE PIPE"
	1	1		A14	2	220 557 20	"SMALL RED WIRE-BUNDLE
1			1	A16	2	152 927 00	"DOUBLE SCREW"
1			1	A18	2	220 557 21	"SMALL GREEN WIRE-BUNDLE
1	1	1	1	A21	4	220 567 77	"GREEN ATTACHING CLAMP"
	1	1		A24	2	992 482 01	"GREEN HEXAGON SCREW"
	1			A28	1	216 259 20	"RED PLASTIC COVER PLATE"
1	1	1	1	A29	4	203 745 01	"BLUE ANGLED BRACKET"
1		1	1	A32	3	216 259 22	"BLUE PLASTIC COVER PLATE"

Fig. 3. The single-kit variant (left) and the batch variant (right) of the paper lists. The columns indicate: storage location, quantity to be picked, part number, description of the part, and checkbox to mark placement. In the right list, the leftmost column (with the "compartment" heading) indicates in which of the four kits to place the picked components and at the same time functions as a checkbox.

The quantitative analysis of the picking time was performed by use of an ANOVA, comparing the average picking time of each of the four different configurations, where the average picking time was measured as the time to perform one picking cycle, divided by the number of components picked during the cycle. Each configuration was represented by a data set of the 50 average picking times that the five pickers together had performed within that configuration. Supplementing the ANOVA, Tamhane's T2 post hoc test was used after testing for, and rejecting, variance homogeneity (Levene statistic, $p < 0.05$). Because the picking errors were relatively few, no statistical analysis was performed of them.

4. Analysis and results

The ANOVA showed that there were significant differences in average picking time between the four configurations ($F = 41.131$, $p < 0.000$). Table 1 displays the average picking times from each of the four configurations. In line with previous research (Hanson et al., 2015), the results indicate that batch preparation is associated with shorter picking time than single-kit preparation. In addition, the results show that configuration 4, where batch preparation was supported by AR, was associated with significantly shorter picking time than each of the three other configurations. The average picking times were shorter for single-kit preparation supported by pick-by-paper than single-kit preparation supported by pick-by-AR, but the difference was not significant at the 0.05 level.

Table 2 displays the picking accuracy of each of the four configurations, measured through the number of picking errors that were made in each of the four configurations in relation to the total number of components picked. In the experiment, pick-by-AR was associated with higher picking accuracy than pick-by-paper, both for single-kit preparation and batch preparation.

5. Discussion

The results indicate that AR can constitute a viable option for conveying picking information. Therefore, it would be fruitful to test and develop pick-by-AR applications further, utilising the findings from the application presented in the paper as a basis. It seems that in batch preparation, pick-by-AR performs significantly better than pick-by-

Table 1
The average time for picking each component in each of the four configurations of the experiment.

Configuration	Picking information conveyance	Batching principle	Average picking time per component (s) ± 95% C.I.	Average picking time significantly ($p < 0.05$) different from that of the following configurations
4	Pick-by-AR	Batch preparation	3.06 ± 0.13	1, 2 & 3
2	Pick-by-paper	Batch preparation	3.50 ± 0.12	1, 3 & 4
1	Pick-by-paper	Single-kit preparation	4.31 ± 0.23	2 & 4
3	Pick-by-AR	Single-kit preparation	4.80 ± 0.40	2 & 4

Table 2
The picking accuracy in each of the four configurations of the experiment, measured through the number of errors in relation to the total number of part numbers picked.

Configuration	Picking information conveyance	Batching principle	No. of errors where either the wrong part number was picked or a part was placed in the wrong kit container	No. of errors in relation to the total number of part numbers picked
3	Pick-by-AR	Single-kit preparation	1	0.13%*
4	Pick-by-AR	Batch preparation	7	0.52%†
1	Pick-by-paper	Single-kit preparation	5	0.67%*
2	Pick-by-paper	Batch preparation	11	0.81%†

* In single-kit preparation, 15 part numbers were picked each cycle, each picker performed 10 cycles in each configuration, and a total of 5 pickers participated – i.e. the denominator is $15 \times 10 \times 5 = 750$.
† In batch preparation, an average of 27 part numbers were picked each cycle, each picker performed 10 cycles in each configuration, and a total of 5 pickers participated. – i.e. the denominator is $27 \times 10 \times 5 = 1350$.

paper, but in single-kit preparation, the differences between pick-by-AR and pick-by-paper were not significant – and the average picking time was actually shorter for pick-by-paper than for pick-by-AR. It could be hypothesised that it is in the type of environment where more information needs to be displayed, such as in batch preparation, that the use of AR is the most beneficial. Studies performed by Iben et al. (2009) and Guo et al. (2015) have indicated that head-mounted displays, not using AR, can support efficiency picking in compact areas. Future studies could further address whether there is an additional efficiency potential associated with the use of AR, compared to the use of 2D information conveyed via head-mounted displays.

In the study, considerably fewer errors were made with pick-by-AR than with pick-by-paper and in association with the study, several of the pickers stated that the picking information was easier to take in with the pick-by-AR application compared to the paper list. While the number of errors registered during the experiment was not large enough to enable a meaningful statistical analysis, the study provides an indication that pick-by-AR holds a potential for supporting a high picking accuracy. This is something that could be addressed in future studies. In this context, it would also be interesting to study combinations of pick-by-AR and different technologies for confirming each pick. In the current study, a voice confirmation was used to indicate that the system should move on to the next part number. There are other technologies that could be tested, which could potentially include a quality inspection, ensuring that the correct component has been picked. For example, RFID tags could be placed on the picker's hands as well as on the bins picked from. Potentially, it could be possible to develop a verification function using high-speed object recognition, integrated with the head-mounted display, but this may be difficult to achieve with today's technology.

Aside of performance in terms of time efficiency and picking accuracy, as measured in the study, flexibility is often a central aspect in the design of kit preparation (Fager, Hanson, & Johansson, 2015). In pick-by-light systems, for example, reconfigurations of the kit preparation area often require physical changes in terms of lights being moved and new wires being connected, which then limits flexibility. In contrast, with the pick-by-AR application that was developed, it was easy to reconfigure the kit preparation area, in terms of changing the locations of the different part numbers or introducing new ones.

The pick-by-AR application was developed specifically for the study and while it was designed with the aim of offering good support to the picker, it is of course likely that the application and the picking performance could be improved further. One thing that was observed during the study was that there could be a potential to improve the efficiency of the single-kit preparation by enabling the picking of multiple part numbers before placing them in the kit container, as opposed to the approach that was used, where the picker would pick one part number at a time and place it in the kit before picking the next part number. However, an approach like this would be associated with a higher complexity and would highlight the question of how each pick should be confirmed in a manner that would ensure picking accuracy.

In the study, a deliberate choice was made to use inexperienced pickers, to enable a fair comparison between pick-by-AR and pick-by-paper. As described in the methodology section, the pickers underwent training before the experiment to minimise learning effects. Nevertheless, the existence of learning effects cannot be ruled out. As found by Grosse and Glock (2013) in the context of warehouse order picking, learning effects can be present over long periods of time and they can vary between individual pickers. In the study, all pickers were relatively young (23–35 years). Potentially, age could be one aspect that affects learning in this context. To be able to observe learning effects, it would be of interest to study a pick-by-AR application over a longer period, preferably in an industrial setting. Such a study could also enable interesting insights into potential ergonomics aspects. A HoloLens weighs close to 600 g and it could be tiring to wear one during a full work shift.

In an industrial application, a choice of which type of system to use for conveying picking information should be preceded by a comprehensive analysis of the available options. Aside of pick-by-AR and the use of head-mounted displays, the most commonly applied options include pick-by-paper, pick-by-light, pick-by-voice, and pick-by-display. The potential of each system to support picking in terms of efficiency, accuracy, and flexibility is essential to consider. In addition, aspects of investment cost and ease of maintenance need to be considered.

6. Conclusions

Based on a realistic experimental setup, developed together with logistics engineers from the automotive industry, the paper has provided insight into how AR can be utilised to support kit preparation in a context of material supply to assembly. Using a novel application, developed in conjunction with the study and tested in an experimental setting, the paper has shown that pick-by-AR can support time-efficient kit preparation, and that it further seems to hold a potential to support both picking accuracy and flexibility in kit preparation. Further research could expand on these findings and study pick-by-AR in an actual industrial setting over a longer period.

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