AR in order-picking – experimental evidence with Microsoft HoloLens

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Abstract

An experiment with 66 subjects was conducted within an augmented reality (AR) order-picking task using Microsoft HoloLens. The objective of the experiment was to test the use of gamification in AR order-picking. Also, another goal was to identify problems in the development of the AR software as well as to detect general problems with the use of AR glasses in warehouse processes. Furthermore the user experience of the application in different age groups and genders was examined. In addition, the influence of the subject's technical affinity was considered. A qualitative survey showed that subjects found the augmented reality application intuitive and satisfying. We want to highlight with this article experimental and technical challenges when using Microsoft HoloLens in real working conditions.

1 Introduction

A technical innovation designed to make warehouse operations easier and more efficient is the introduction of data glasses. Data glasses are used to assist workers in order-picking. Goetschalckx and Ashayeri (1989) defined order-picking as "the activity by which a small number of goods is extracted from a warehousing system to satisfy a number of independent customer orders". Generally speaking, it's about putting correct packages together in a warehouse. Using augmented reality to support order-picking-processes has already recently shown to be a valid option, because it can help to reduce picking time and enhance picking accuracy (Hanson, Falkenström, & Miettinen, 2017).

There are currently several different AR glasses available. However, they differ greatly in terms of their field of view, their battery power, their weight and some other important parameters. A comparison of some up-to-date glasses is provided in table 1.

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Model	Battery	Beacon for in-room-navigation	Additional device required	Weight	Field of view	Price	OS
Epson Moverio BT-300	6 hours via external battery	Yes	Yes	69g	23°	850€	Android
Google Glas	1 hour	Yes	Yes	42g	14°	1500€	Android
Meta 2	powered by cable	No	Yes	500g	90°	1700€	Windows
Microsoft HoloLens	4 hours	No	No	580g	35°	5000€	Windows
Smart-Eyeglass SED-E1	2.5 hours	Yes	Yes	77g	20°	800€	Android
Vuzix M300	2 hours	Yes	Yes	110g	15°	1700€	Android

Table 1: comparison of common AR glasses

The concept of our study was to make an AR order-picking task more motivating by using gamification. For this purpose, two game design elements were integrated into the application: badges and a leaderboard. To be able to represent this additional information in a sensible way, a large field of view is an important requirement for data glasses. Additionally, in order to obtain valid test results, it was planned to test a group of at least 60 subjects. Because it is desirable not to have to charge the device between each test run, a long battery life is necessary. Our final requirement was to have navigation as precise as possible, in order to be able to find smaller objects in a warehouse without any problems. Our requirements were met by the two data glasses: Meta 2[1] and Microsoft HoloLens. However, Meta 2 is not suitable in order-picking tasks, since the glasses must be connected via a cable to a computer. So we decided to use the Microsoft HoloLens, one of the most popular AR glasses right now (Fraga-Lamas, Fernandez-Carames, Blanco-Novoa, & Vilar-Montesinos, 2018).

[1] https://meta-eu.myshopify.com/#specifications

2 Study

An AR order-picking application was implemented for our study. Our application basically consists of four components: the routing, the storage compartments, a QR code scanner and two gamification elements, which served as experimental manipulation. The subject's task was to pick orders in an experimental setting within a simulated warehouse. During the study, the participants are guided by the glasses through the warehouse.

2.1 Design

The routing is based on the in-room-navigation of the HoloLens. By using the spatial mapping of the HoloLens, a virtual model of the room is created. This model is used to preposition waypoints and shelf markings on the computer in Unity[2]. Unity is a freely available game engine, that is used for the development of HoloLens applications and makes it possible to create and edit 3D game worlds using a graphical interface. The application shows a green path to lead the user through the warehouse, as depicted in figure 1 on the right. The path guides the user to the next destination along predefined waypoints in the warehouse. The application always determines the shortest route to the next product in the picking order, using the Floyd-Warshall algorithm[3]. Red rectangles are displayed at the end of the path to highlight the current shelf, see figure 1 left. As an additional mechanism, a QR code scanner has been integrated into the application. If a subject clicks on one of the red shelf markers, the camera of the HoloLens is activated. The user checks the correctness of each of his/her picks, by scanning each product he/she takes from the shelf. In addition the subjects also see a list of all items in the current order in the lower-right corner of his/her field of view (figure 1 right). If an item is successfully picked and the correctness of the pick is confirmed by scanning the correct QR code, the corresponding item will be crossed off the order list.

Figure 1: Red shelf marking, view of the navigation and order list

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[2] https://unity3d.com/

[3] Floyd, R. W. (1962). Algorithm 97: Shortest path. *Communications of the ACM 5*(6), 345.

The experiment consists of four phases: greeting, tutorial, picking and post-test. On average, the duration for running the experiment was about 30 minutes. In the first phase (greeting), the subjects were briefly explained that this is an experiment in the field of order-picking with AR and how they can put on the HoloLens. The tutorial consists of a first test order to be picked by the subjects. During the picking phase all subjects had to compile the same ten orders, which totaled in 37 picks. The post-test consists of a questionnaire which was conducted after the experiment.

Based on the results of Joseph, Gabbard, Swan and Hix (2006) textual information of the order list was displayed in billboard style. The text instructions during the tutorial were given with no background, so as not to restrict the field of view. For all objects, such as the path, the shelves and the game design elements, bright colors were chosen, as they are better visualized on the HoloLens and are easier to perceive (Zimmer, Bertram, Büntig, Drochtert, & Geiger, 2017).The waypoint collider has been made larger than the optically visible object, making it easier to get triggered, even if the subject does not follow the path exactly.

One of the main challenges with the development was that the user always had to stand at the beginning at a specific point in the room. The reason for this is that the spatial model can't be reversed back to the real space. The model can only be used to position objects at the correct distance, but not to position them correctly in the warehouse in advance. To deal with this issue, a menu has been designed that allows the position of objects to be readjusted after the application has started. This is an important issue and makes the general usefulness of our study scenario questionable, as in real life this might be not always possible.

During the pre-test it was often unclear whether a subject had actually clicked on an object correctly. In order to make the interaction with objects simple and clear, an acoustic signal has been integrated into the application that confirms the successful completion of a click. Also Zimmer et al. (2017) point out that the triggering of an action should be confirmed with feedback, keeping in mind that unexpected or improper feedback can be a considerable drawback (Mazarakis, 2015), but which was not the case in our study.

2.2 Method

In our study, numerous variables were collected via HoloLens, e.g. the number of correctly collected items and the time required to complete each order. The variables were collected to find out if the speed of task completion or the error rate would be influenced by factors such as age, sex, or technical affinity. In addition, further data was collected by means of a questionnaire at the end of the experiment.

The questionnaire revealed the age, gender and profession of the subjects, as well as their motivation and satisfaction during the experiment. In addition, the Affinity for Technology Interaction (ATI) scale was integrated into the survey. This scale was developed by Franke, Attig and Wessel and it is used to assess users affinity for technology, with focus on user-system interaction (Franke, Attig, & Wessel, 2017). The ATI was included in the questionnaire to investigate whether subjects' technical affinity may have an impact on their performance or motivation during the trial. The questionnaire consists in total of nine items.

2.3 Participants

In total, 80 participants took part in the experiment and completed the questionnaire. During the data clean-up 7 participants were sorted out due to technical problems and 10 because they did not comply with the experimental manipulation and there was serious concern, that they did not understand the task at all.

Thus, the sample consists of n = 63 subjects. Of these, 35 are students (55.6 %), 27 employees (42.9 %) and 1 self-employed individual (1.6 %). 32 of the subjects were men (50.8 %) and 31 women (49.2 %). The average age is 30.92 years (standard deviation 10.84). The youngest individual is 19 years old and the oldest is 60 years old. In total, 9 of the subjects (14 %) already had experience in order-picking.

3 Results

In this section descriptive and inferential results are presented first, followed by qualitative results of the study.

3.1 Statistical evaluation

On average, the subjects needed 751 seconds (standard deviation 149 sec.) to complete the course. The fastest subject needed only 501 seconds and the slowest 1168 seconds. If you look at the average values divided by gender, you get a total of 705 seconds for men (standard deviation 154 sec.). The average time of women was much higher with 798 seconds (standard deviation 128 sec.).

The average task motivation according to the questionnaire was 5.07 (standard deviation 1.61). Since the scale ranged from 1 to 7, the mean seems to indicate that the subjects are feeling motivated. The same applies to the task satisfaction of the subjects for which a mean value of 4.77 (standard deviation 1.65) was recorded.

There was a strong negative correlation between gender and ATI, $r = -.495$, n = 63, $p = .000$. Since men were coded with 0 and women with 1, this means that men were much more technically affine than women.

Another assumption was that the AR application may be adopted differently by different age groups. No significant correlation was found between the age of the subjects and their technical affinity, $r = -.136$, n = 63, $p = .288$, their motivation, $r = -.204$, n = 58, $p = .125$ or satisfaction, $r = -.236$, n = 62, $p = .064$. However, a weak correlation could be established between the age of the subjects and the time to complete the course, $r = .296$, n = 63, $p = .018$. It can be assumed that age has no influence on the user experience of the AR application.

There was a statistically significant medium correlation between the overall satisfaction during the task and the ATI, $r = .358$, n = 62, $p = .004$ A statistically significant weak correlation was found for the overall motivation and the ATI, r = .308, n = 58, p = .019. It can therefore be concluded that users' technological affinity has a positive impact on their user experience when using AR-applications. No statistically significant correlation between technical affinity and the time the subjects needed to process the orders could be determined, r = -.221, n = 63, p = .082.

3.2 Qualitative investigation of user comments

The objective of the user survey was to identify problems in the development of the application as well as to identify general problems with the use of AR glasses in warehouse processes. A total of 22 subjects have commented on the experiment. Of these, 13 contained criticisms like complaints about usability, the remaining comments contained only general remarks about the experiment like "it was fun".

The main issue for the subjects was the weight of the HoloLens. Many subjects complained that the glasses were either too heavy and pushed too hard on the nose or are in general too heavy and uncomfortable to wear. This is the case for 2/3 of the subjects, either written in the comments of the questionnaire or stated orally during the experiment. This problem has already been criticized in another study (Velamkayala, Zambrano, & Li, 2017). Also adjusting the glasses seems to be difficult. Many subjects had problems placing the glasses so that they could not see the field of view completely and the glasses did slide down. The experimenter had to ask repeatedly whether all elements were visible and where the cursor was located, which marks the center of the field of view. As a result, the subjects needed a bit longer to complete the tutorial or end up with the problems.

Another technical problem, which was very common during the experiment, was locating in room. During the experiment, the HoloLens regularly lost the orientation and had to reposition itself. A possible explanation for this could be the surfaces on the test course, which were very monotone (walls with shelves), or the distance to the wall was too close when standing directly in front of the shelfs (Peter_NZ, 2017). This is rather restrictive, because the experiment aimed to simulate in a very realistic way the effectiveness for an order-picking scenario. If these challenges persist in further to conducted experiments, then the use of Microsoft HoloLens is only sensible in open areas without many obstructing walls.

Other issues concern the implementation of the application. At the beginning, voice control had been used so that the user had both hands free to work. However, during a pre-test phase, speech recognition was severely impaired by slight ambient noise. Only at almost silent situations speech recognition worked well, which is unrealistic for normal working conditions. For this reason, speech recognition was removed and replaced with a clicker control. This clicker control is used to confirm picks and start the QR code scanner. Still, it is problematic that the user has only one hand free, same as picking with paper lists. In retrospect, it turned out that possibly the design of the voice command could have led to the problems. Contrary to Microsoft's suggestion, just a single syllable word was used (Eveleigh, 2018).

Another point noted was that the navigation path was often hard to see. It was possible to select one of two options for the height of the path according to the subjects' height. Nevertheless, there were some problems, as the field of view of the HoloLens, although it is relatively large (35°) compared to other glasses, is limited. Microsoft itself pretends to be plotting holograms at a distance of between 1.25 m and 5 m (beaufolsom, 2018). It often happened that subjects had to take a few steps to the side in order to be able to recognize virtual objects lying very much in front of them or not directly in the center of the field of view. Due to the limited field of view, a simple navigation that displays arrows in the user's field of vision might be preferable, like the one introduced by Schwerdtfeger and Klinker (2008).

From a plus side, several subjects also noted that they would be able to do their job very easily after a short time. With the support of AR, the candidates could carry out the activity after the short five-minute instruction. A significant shortening of the learning phase through the use of AR has already been confirmed in practice. (Deutsche Post DHL Group, 2017).

At the beginning of the experiment, people's skepticism about the new technology also posed a minor problem. The potential participants had heard of the problem of cybersickness and therefore shied away from participating in the experiment. Only after some detailed explanations and the reports of the first subjects, the subjects agreed to participate in the experiment.

4 Conclusion

This study showed that AR has the potential to make work processes easier and more intuitive. However, the underlying technology still requires further development, in particular with regard to wearing comfort. The evaluation of the comments suggests that a longer-term use of the HoloLens in the warehouse at the current level of development is due to the weight is not advisable.

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