Extended Investigations of User-Related Issues in Mobile Industrial AR

Jens Grubert*
Fraunhofer Institute for Factory Operation and Automation IFF

Daniel Hamacher
Otto-von-Guericke University Magdeburg

Rüdiger Mecke
Fraunhofer IFF

Irina Böckelmann
Otto-von-Guericke University Magdeburg

Lutz Schega
Otto-von-Guericke University Magdeburg

Anke Huckauf
Ulm University

Mario Urbina
Ulm University

Michael Schenk
Fraunhofer IFF

Fabian Doil
Volkswagen AG

Johannes Tümler†
Volkswagen AG

Abstract

The potential of Augmented Reality (AR) to support industrial processes has been demonstrated in several studies. While there have been first investigations on user related issues in the long-duration use of mobile AR systems, to date the impact of theses systems on physiological and psychological aspects is not explored extensively. We conducted an extended study in which 19 participants worked 4 hours continuously in an order picking process with and without AR support. Results of the study comparing strain and work efficiency are presented and open issues are discussed.

Index Terms: H.1.2 [Models and Principles]: User/Machine Systems—Human factors; H.5.1 [Information Interfaces and Presentation]: User Interfaces—User-centered Design

1 Introduction

The potential of AR to support workers in industrial scenarios has widely been researched in projects like ARVIKA, ARTESAS and AVILUS. Such industrial scenarios are characterized by full-shift continuous use of AR systems, rough and dynamic environments as well as very inhomogeneous user groups. Investigation of user-related aspects of AR systems in industrial settings was no major topic in the last decades. This is due to several factors including current immature AR hardware and user interfaces, high safety demands from industrial partners, difficulties to implement prototypical AR systems into productive work processes and thus high costs of conducting studies outside the laboratory. Recently, a few approaches have been undertaken to study effects of AR systems on users in industrial like settings [4, 3]. In [4] the use of AR in industrial environments using the example of order picking (paper list and an AR system employing a 2D navigation visualization) was investigated. This evaluation focused on measuring strain by analyzing heart rate variability (HRV) during a two hour work phase. No significant differences between work with AR and without AR system could be found. However, participants complained about eye discomfort. Two studies carried out by Schwerdtfeger et al. focused on strain and work efficiency analysis [3]. While no increase of user strain could be detected in a work phase of two hours, several subjects complained about head and eye discomfort. The employed AR systems were not able to significantly perform better in terms of error rates or number of picked items in comparison with non AR supported work.

Our study builds up on these experiments by investigating user strain and work efficiency for a prolonged time of use (4 hours) and by revising the employed investigation methods.

*e-mail: jg@jensgrubert.de
†e-mail: johannes.tuemler@volkswagen.de

IEEE International Symposium on Mixed and Augmented Reality 2010
Science and Technolgy Proceedings
13 -16 October, Seoul, Korea
978-1-4244-9345-6/10/$26.00 ©2010 IEEE

2 Revising the Reference Work Scenario

We revised our investigation methods and the employed AR system from a previous study [4] to both be able to better understand observations of the first study and to support the work task with a more mature system.

Analysis of questionnaires of the previous study [4] revealed that eye and head discomfort could be induced by the system for some users. Therefore, we introduced ophthalmological checks to allow relating possible strain and work efficiency data to visual deficiencies of subjects. This check also allowed to secure that participants did not show significant visual problems which would render them unsuitable for the study. It allows the evaluation of several visual functions (see [1] for details). In addition we used a test for split attention, in which participants conduct a dual-task by reacting on simultaneous visual and auditive stimuli. Furthermore, we switched from a MT-101 Holter-ECG to the pulse clock Polar RS800CX for recording ECG raw data as it allows to more precisely capture parameters in the time and frequency domains.

(a) (b)

Figure 1: Current iteration of the AR system: Liteye HMD, infrared outside-in tracking, attention funnel navigation.

The previously employed optical see-through head mounted display (HMD) Microvision Nomad ND2100 presents information in monochrome red. A stable mounting of the display on users' heads required firm adjustment of the Velcro band which resulted in head pressure with subjects as was shown in [2]. The LitEye LE-750A (see Figure 1(a)) offers similar see-through rates to the Microvision Nomad2100. In addition, the LE-750A offers a sturdier built and contents can be displayed in color. Furthermore, it can be combined with various mounts. We chose a Carl-Zeiss mount ("System Mount S") which is also employed in surgical operations. We adopted the inside-out tracking approach presented in [3] and employed an optical outside-in 60 hz tracking system by A.R.T. To tackle shortcomings of the 2D-arrow visualization of [4] we employed an attention funnel metaphor for target visualization [3] (see Figure 1(b)) developed by metaio GmbH. In conjunction with the outside-in tracking system the visualization allowed a continuous and unambiguous navigation support. Furthermore, we introduced a single-button interaction device worn on users' hips to allow for undoing a confirmation of a wrongly picked item.

3 USER STUDY

This study aimed at getting insights about user strain, discomfort and work efficiency in a prolonged work duration of 4 hours. We built on experiences made in previous studies [4, 3] and describe changes and similarities as appropriate.

Test Setup and Procedure We used the test setup described in [4] and extended it according to the changes described in section 2. The study was run with 19 participants (mean age 26.5, σ 3,8 years, 17 males, 2 females). Ten participants did not have any experience with AR and picking systems. Four participants already used picking systems and 7 had experience with AR or VR systems.

The test was executed as described in [4] with following exceptions. Prior to working at the reference work scenario all subjects had to conduct an ophthalmological check on a separate day. On the two days of the test (one day for the work with the AR system, the other for work without AR support or vice versa) subjects executed the split attention task in a pre-test and post-test phase in addition to answering questionnaires for recording subjective strain indicators. The main work phase was divided in a 135 minutes work phase, a 5 minute battery changing phase and another 100 minutes work phase.

Hypotheses We expected that the toll of carrying additional hardware and processing additional visual information would show after an extended work period of 4 hours. As we optimized the employed AR system we also expected that the work efficiency (i.e., lower error rates, higher number of picked items) with the AR system would be higher than with a paper list. Therefore our hypotheses were. H1: *The overall objective and subjective strain is higher with the use of the AR system than without it*. H2: *Work efficiency is higher wit AR support than without.*

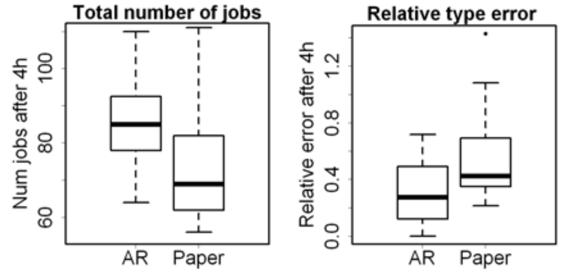
Results For the HRV analysis the standard deviation in the time domain was chosen. It indicates changes in the user strain through short term changes of the sympathetic and parasympathetic nervous system. There were no significant differences between work with and without AR system. The analysis of the EZ-scale and sensitivity scale were analog to the results in [4]. Therefore, hypothesis H1 was rejected.

The discomfort questionnaire was focused on visual discomforts. Nine of 19 subjects indicated increased visual fatigue with the AR system. Three of those 9 subjects showed a reduced contrast sensitivity but nonetheless had good visual acuity. In addition, only participants with diminished stereopsis and participants with increased intraocular pressure indicated increased visual fatigue. No other correlation between parameters of the ophthalmological check and discomforts were found. The split attention test showed no significant differences in pre-post comparison for work with and without AR.

In contrast to previous studies [4, 3] participants collected significant more items with AR support than without ($p = 0.002$, Wilcoxon signed-rank test, in average 13 % more items, see Figure 2(a)). The error analysis revealed that work with AR support resulted in significant less type errors ($p = 0.007$, Wilcoxon signed-rank test, see Figure 2(b)). Regarding the amount error (more or less than 15 items picked) there was no significant difference. Overall, we could confirm hypothesis H2.

4 DISCUSSION AND CONCLUSION

The analysis of objective and subjective strain measures were consistent to the results of previous studies [4, 3]. This indicates that the employed AR system does not increase users' overall objective and subjective strain. Nonetheless, some users perceived increased eye discomfort. The ophthalmological check revealed that users with visual deficiencies tend to experience visual discomfort more likely than users without visual problems. Nonetheless, a goal for industrial AR systems should be to be usable by a wide range of



(a) (b)

Figure 2: With AR support significantly more items were picked (a) and significantly less type errors were made (b).

users (more than the 80 % reported in previous experiments). When this cannot be achieved ophthalmological checks should be used to identify users that could likely experience discomforts when using AR systems.

In comparison with previous studies [4, 3] both error rates were significantly lower and picking rates higher for the work with AR system than for work without AR support. This could be due to the system optimizations, especially due to the attention funnel and reduced system latency. However, it is unclear whether the work efficiency gain reported in this study can be confirmed in a real production environment. Participants were mainly students - not professionals. Therefore, further studies with professionals should be conducted.

While the redesign of the AR system led to a work efficiency gain, employing the attention funnel metaphor raises questions about an appropriate level of support of an AR system. The attention funnel is a constant navigation aid which ties users' attention. This can result in inattentional blindness [5] and therefore potentially harm users in a work process. Further studies will be conducted to investigate this phenomenon in HMDs.

ACKNOWLEDGEMENTS

This work was supported in part by a grant from the German Federal Ministry of Education and Research (AVILUS project, grant no. 01 IM08001 L)

REFERENCES

[1] I. Boeckelmann and E. A. Pfister. *Handbuch der betriebsaerztlichen Praxis. Grundlagen - Diagnostik - Organisation - Praevention - Rechtskommentare ("Handbook for practices of company physicians: diagnosis - organization - prevention - legal commentaries")*, chapter Untersuchungen des Sehvermoegens ("Investigations of eyesight"), pages 1–32. Hofmann, F and Kralj, N, 2007. ISBN 3-609-10230-6.

[2] J. Grubert, J. Tuemler, R. Mecke, and M. Schenk. Comparative user study of two see-through calibration methods. In *Proceedigns of the IEEE Virtual Reality Conference 2010 (VR 2010)*, Waltham, Massachusetts, USA, 2010.

[3] B. Schwerdtfeger, R. Reif, W. A. Guenthner, G. Klinker, D. Hamacher, L. Schega, I. Bockelmann, F. Doil, and J. Tuemler. Pick-by-vision: A first stress test. In G. Klinker, H. Saito, and T. Höllerer, editors, *ISMAR*, pages 115–124. IEEE Computer Society, 2009.

[4] J. Tuemler, R. Mecke, M. Schenk, A. Huckauf, F. Doil, G. Paul, E. A. Pfister, I. Boeckelmann, and A. Roggentin. Mobile augmented reality in industrial applications: Approaches for solution of user-related issues. In *Proceedings of the Seventh IEEE and ACM International Symposium on Mixed and Augmented Reality 2008 (ISMAR08)*, pages 87–90, Cambridge, UK, 2008. IEEE Press.

[5] C. Wickens and A. Alexander. Attentional tunneling and task management in synthetic vision displays. *International Journal of Aviation Psychology*, 19(2):182–199, 2009.