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User expectations on smart glasses as work assistance in electronics manufacturing

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Abstract

The research project Glass@Service addresses the development of components and services for augmented reality smart glasses as work assistance in electronics manufacturing. In this context the Federal Institute for Occupational Safety and Health planned and implemented an evaluation of these assistance technologies in selected work places: In two use cases – order picking and setup of assembly machines – a survey with a total of 59 employees was conducted in order to analyze variables such as mental strain, usability or user acceptance. In this article the results of the first survey about user expectations towards the usability, usefulness and acceptance are presented.

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Keywords: Augmented reality smart glasses; usability; technology acceptance; user expectations

1. Introduction

The implementation of technological innovations is a key factor for ensuring the competitiveness of companies [1]. At the same time, companies also have an interest in maintaining the health and well-being of their employees. The collaborative research project Glass@Service addresses among other things the development of components and services for augmented reality smart glasses, which should consider these two requirements synergistically on the basis of two use cases in electronics manufacturing. One goal is the integration of innovative components in intelligent see-through smart glasses and the related services to support industrial employees [2, 3].

In this context, the approach of the Federal Institute for Occupational Safety and Health is the consideration of ergonomic design capabilities in order to develop stress optimized and safe concepts for augmented reality smart glasses as work assistance. Using electronics manufacturing as an example, chances and risks of these kind of smart glasses, especially towards the long-term use in real industrial work processes, have to be pointed out [4]. For this purpose, the influence of such technologies on mental strain, acceptance, and usability should be analyzed. [5, 6]

This is to be achieved by an accompanying human factors research, which will continuously evaluate the implementation and use of the developed smart glasses as work assistance in the use cases of the project. For this purpose, a total of 59 employees were surveyed prior to the technology implementation in two use cases. After the implementation of the work assistance and after possible changes in the work content or processes, this survey will be repeated in regular intervals. The collected data represent a subjective perception towards the variables usability, short-term mental strain and perceived usefulness. This paper presents and discusses the results of the first survey about the user expectations on the new work assistance as well as the further approach for the ergonomic evaluation during the project.

2. The project Glass@Service

The Project Glass@Service was launched to further promote the current state of the art in the field of smart glasses and, in particular, to resolve existing restrictions on

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the use as work assistance in an industrial environment. Current technologies – monocular as well as binocular – do not have the properties necessary for an industrial use. Furthermore, in the technologies, which are currently available and usually developed for the consumer market, aspects such as battery life, wireless network connections, object and scene tracking etc. are not suitable for environments, in which high demands on network security, safety, production accuracy etc. prevail. Furthermore, least smart glasses are suited for spectacle wearers. For these reasons, in the project Glass@Service new smart glasses are being developed, which take the requirements of an industrial use on the basis of following three use cases into account:

- Order picking in warehouse logistics,
- Setup of assembly machines,
- Visual quality inspection.

Based on a benchmark on smart glasses and the integrated technology currently available on the market, the specification sheet was composed. The main requirement from the point of view of occupational safety and health is to develop a technology, which is safe in its use, comfortable with a high acceptance of the employees, suited for all kind of spectacle wearers and approved as safety glasses. Technological requirements for the innovative smart glasses are inter alia: camera functionalities, see-through technology, not less than eight hours battery life, augmented reality (AR) functionalities, object tracking, wireless network, Bluetooth, voice and gesture control. Therefore, among other things the following components will be considered in the development:

- Scene camera,
- Time of flight camera,
- Eye-tracking camera,
- Micro-displays,
- Achromatic lenses,
- Brackets for individual spectacle lenses.

The development of the hardware and software of the work assistance is parallelized. For this purpose the first use case (order picking) is implemented by software on smart glasses, which are currently available on the market. In the second use case (setup of assembly machines) follows the transition to the first developed demonstrator for test purposes. Finally the optimized software and hardware will be merged in the third use case (visual quality inspection). Because of the chronological sequence in the project early studies are conducted for the first and second use case, which are briefly introduced in the following.

2.1. Use Case 1: Order picking in warehouse logistics

The first use case is about order picking in the small parts warehouse. Currently, the picking lists and labels are being printed stationary and the employees are manually selecting their work orders. The employees start the process by going to the storage bins with the printed paper lists and labels. Subsequently, the material number in the small load carrier is compared to the corresponding number on the picking list before the material is finally picked. The picked material is collected in bags or small load carriers, equipped with the labels and acknowledged using paper and pen. Finally, the material is passed to the subsequent process.

With smart glasses, the work process is to be made lean. The previous paper-and-pencil method is digitized. As soon as an employee is free, he receives a picking order on the smart glasses about five positions, which are displayed to him one after the other. Therefore, he receives the information about the storage bin, the material number and the required quantity in the single view. The storage racks and bins are visually highlighted for navigation purpose. The picking process is started by scanning the barcodes of the storage bin and the material number. After removing the material, the picked quantity is acknowledged via voice control or touchpad. The required labels will be created automatically by a mobile printer and then attached by the employee. Finally, the storage bin is scanned again, which causes the next order to appear.

2.2. Use Case 2: Setup of assembly machines

The second use case deals with the setup of surface mounted device (SMD) assembly line. Here, the employees must observe a so-called hit list on a stationary monitor, on which the assembly lines to be setup are displayed ordered by the time to idle. The material requirements and the corresponding storage bin have to be identified. The employee goes to the storage bin, removes the component reel by use of a stationary PC terminal and brings it to the assembly line. There, the feeder track to be equipped is identified, the old component reel removed and connected to the new component reel. Subsequently, the feeder track, the old component reel and the new component reel must be scanned successively with a handheld PDA.

The purpose of the smart glasses is to eliminate the constant observation of the stationary monitor. The setup orders are automatically assigned to the employees and displayed by the smart glasses. If the setup order is manually accepted – voice control or touchpad – the storage out-sourcing order is initiated automatically. At the assembly line itself, the feeder track to be setup is visually highlighted. The scanning of the track and the component reels is done by smart glasses. Finally, the work order can be acknowledged.

3. Design of the study

The research question of the Federal Institute for Occupational Safety and Health is about chances and risks of smart glasses as work assistance in an industrial environment. In this context a study by means of a systematic review was conducted, which examined the evaluation of smart devices as work assistance [4]. The aim of the review was to investigate, if there are specific methods and criteria to evaluate the usability and acceptance of smart devices or how far consisting methods including their criteria from the area of conventional screen work can be adopted. Among other things the review showed that the majority of studies about smart devices are dealing with smartphones instead of smart glasses or other innovative technologies with high potential as work assistance. Furthermore, the amount of studies increased in the last years, but only a small number of studies describe a potential use of innovative technologies for work applications [4]. Against this background, the goal of the survey presented in this article is to evaluate the work assistance system by a pre-post comparison within the use cases. This article presents the survey of the user expectations within the first two use cases (see above) considered in the project - order picking in the warehouse logistics and setup machines of a SMD assembly line.

3.1. Method

Due to a restricted comparability between the use cases and other workplaces in the company a within-subject-design with one sample each was chosen for the evaluation study. For the analysis, described in this paper, the data of the preliminary survey about the user expectation existed. The user expectations on the usability were surveyed quantitatively via questionnaires based on the principles governing the design of software dialogue according to DIN EN ISO 9241-210 [7]. The expectations towards the perceived usefulness and the user acceptance were based on the Technology Acceptance Model [8]. Prior to the survey, all participants were informed about the project and the work assistance system.

After a first test phase of the prototypical work assistance system and during further use, the usability as well as the perceived usefulness and user acceptance will be surveyed in regular intervals by questionnaires.

3.2. Sample

A total of N = 59 employees took part in the survey, of which N = 17 (4 females, 13 males) employees are situated in the first use case (order picking) and N = 42 (39 females, 3 males) employees in the second use case (SMD setup). In the first use case the subjects represent a sample of 70.83 % of the population – based on an assumed population of N = 24 persons, which are employed in this workplace. In the second use case it was possible to conduct a complete survey with an assumed population of N = 42 employees.

It was noticeable, that the average age in the first use case was significant higher compared to the second. The participation in this survey was voluntary for the employees in both use cases.

3.3. Material

The user expectation data in terms of the usability were collected by means of a self-developed short questionnaire; each of the seven dialog principles (suitability for the task, learnability, self-descriptiveness, controllability, conformity with user expectations, error tolerance and suitability for individualization) was integrated in one question [7]. Furthermore, there were two questions each about the perceived usefulness, perceived ease of use and the affective state as dimension of the user acceptance [8]. All answers were made on a 5-point Likert scales (1 = not true, 5 = true).

For data protection reasons, the age could not be used officially as a control variable in the statistical evaluation and is only reported as observation by the study leader.

3.4. Statistical evaluation

Due to the sample size compared to the population of each use case, parametric methods were used for the inferential statistical analysis. A one-sample *t*-test was considered as robust enough and was calculated for the seven dimensions of usability, the two variables of the perceived use as well as for the technology acceptance. The objective was to point out increased or rather particularly low expectations prior to the implementation of the new work assistance. Based on the complete survey in the second use case, the first use case was additionally tested against the real averages of the second use case. In doing so, possible tendencies in the group comparison could be analyzed. The error probability for the α-error was set to 5 % for all analyses in a two-sided test.

4. Results

The analysis of the user expectations in the first use case by means of the *t*-test shows as a result, that regarding to the usability the mean score of the dimension error tolerance ("operator errors do not lead to serious consequences") was statistically significantly lower by 0.76 (95 % CI, 0.12 to 1.40) than a normal expectation score of 3.0, $t(16) = -2,519$, $p = .023$. Similarly, the expectations on the perceived usefulness was statistically significantly lower by 0.68 (95 % CI, 0.09 to 1.26) than a normal expectation score, $t(16) = -2,466$, $p = .025$. The remaining six dimensions of usability as well as the perceived use and affective state did not differ statistically significantly from a normal expectation score of 3.0.

In the second use case the mean score of the dimension learnability (3.67 ± 0.65) was statistically significantly higher by 0.67 (95 % CI, 0.46 to 0.87) than a normal expectation score of 3.0, $t(41) = 6.645$, $p = .000$ as well as the conformity with user expectations with a statistically significant difference of 0.33 (95 % CI, 0.12 to 0.55), $t(41) = 3.146$, $p = .003$. Furthermore, in the case of technology acceptance, the mean score for the perceived ease of use (3.38 ± 0.60) was statistically significantly higher by 0.38 (95 % CI, 0.19 to 0.57) than a normal expectation score of 3.0, $t(41) = 4,095$, $p = .000$. The remaining five dimensions of usability as well as the expected utility and perceived use and affective state did not differ statistically significantly from a normal expectation score. The results of the statistical evaluation of the user expectations in both use cases in comparison to a normal expectation score of 3.0 are shown in Table 1.

Table 1: one-sample *t*-test of the user expectations compared to a normal expectation score of 3.0

Variable	test value = 3				
	N	*M*	*SD*	*df*	*p*
Suitability for the Task					
use case 1	17	2.47	1.23	16	.10
use case 2	42	3.17	.82	41	.20
Learnability					
use case 1	17	3.06	1.39	16	.86
use case 2	42	3.67	.65	41	.00
Self-Descriptiveness					
use case 1	17	2.53	1.28	16	.15
use case 2	42	3.00	.88	41	1.00
Controllability					
use case 1	17	2.82	1.33	16	.59
use case 2	42	2.88	.89	41	.39
Conformity with User Expectations					
use case 1	17	3.18	.24	16	.57
use case 2	42	3.33	.69	41	.00
Error Tolerance					
use case 1	17	2.24	1.25	16	.02
use case 2	42	2.93	1.05	41	.66
Suitability for Individualization					
use case 1	17	2.65	1.22	16	.25
use case 2	42	2.95	.96	41	.75
Perceived Usefulness					
use case 1	17	2.32	1.13	16	.03
use case 2	42	2.90	.84	41	.46
Perceived Ease of Use					
use case 1	17	2.97	1.24	16	.92
use case 2	42	3.38	.60	41	.00
Affective State					
use case 1	17	2.88	1.24	16	.70
use case 2	42	3.26	.97	41	.09

M = mean, *SD* = standard deviation, *df* = degrees of freedom

Due to the different work contents of the two use cases, initially it was dispensed with a statistical group comparison. However, as the second use case was a complete survey, it was used to test the results of the first use case against this real mean instead of a normal expectation score of 3.0. Thus, the results of the first analysis were reviewed by means of a de novo one-sample *t*-test with respect to the real mean scores of the second use case. By using the mean scores, which are presented in Table 1, the results of the comparison between the first use case and the second one are aggregated in Table 2. It shows that the user expectations in the first use case compared to the second use case differ statistically significantly in two dimensions of usability. At first the mean score of the dimension suitability for the task was statistically significantly lower by 0.70 (95 % CI, 0.06 to 1.33) than the test value of 3.17, $t(16) = -2.332$, $p = .033$. As well the mean score of the dimension error tolerance (2.24 ± 1.25) was lower than the appropriate test-value of 2.93, a statistically significant difference of 0.69 (95 % CI, 0.05 to 1.34), $t(16) = -2.284$, $p = .036$. The remaining dimensions did not differ statistically significantly between the use cases.

In comparison of the individual aspects of technology acceptance, the perceived usefulness was statistically significantly lower by 0.58 (95 % CI, 0.00 to 1.16) than the appropriate test-value of 3.17, $t(16) = -2,119$, $p = .050$). The remaining two aspects did not differ statistically significantly between the use cases.

Table 2: One-sample t-test to analyze the user expectations in use case 1 against the real mean scores of use case 2

Variable	*df* = 16	
	t	*p*
Suitability for the Task	-2.33	.03
Learnability	-1.80	.09
Self-Descriptiveness	-1.52	.15
Controllability	-0.18	.86
Conformity with User Expectations	-0.52	.61
Error Tolerance	-2.28	.04
Suitability for Individualization	-1.03	.32
Perceived Usefulness	-2.12	.05
Perceived Ease of Use	-1.36	.19
Affective State	-1.26	.23

df = degrees of freedom, *t* = t-value of the one-sample t-test

5. Discussion

Considering the collected data, the overall user expectations in the second use case are more positive across all asked dimensions of usability and acceptance than in the first use case. In detail, there are statistically significant differences in the usability dimensions suitability for the task and error tolerance as well as for the perceived usefulness. However, the last two mentioned variables scored below a normal expectation level of 3.0 in the second use case as well. A first explanatory approach is the task-technology-fit, which particularly is important with regard to smart glasses and may have an impact on the acceptance or the expected usefulness [9]. Potential age effects could also be incorporated here, as the average age differs noticeably between the two use cases. Overall, it should be noted that due to the structurally different use cases, there is only a limited comparability.

The results in the first use case demonstrate statistically significantly lower expectations than a mean expectation score in terms of error tolerance and perceived usefulness. In combination with the low score in the suitability for the task described above, this may indicate that the employees do not assess smart glasses as a suitable work assistance in the first use case the application prior to an implementation and test. This can also be an explanation for the overall rather low user expectations.

In contrast to the first use case there are more positive user expectations in the second use case. In particular, the aspects learnability and perceived ease of use have statistically significantly higher scores than a normal expectation score of

3.0. A possible explanatory approach may also be the lower average age, which may be associated with a higher affinity to modern technologies from the consumer sector [10]. Another influencing factor can be the noticeable more pronounced use of technology in the second use case, by which the use of modern technologies does not result in a major change in the existing work structures.

6. Conclusion

The results of the first survey demonstrate notable differences in the user expectations between the two considered use cases and a mean level of expectation. While the expectations are in part significantly below a mean level of expectation in the first use case, the expectation level in the second use case is notably higher. In a direct comparison of the two use cases, the expectations towards the suitability for the task, the error tolerance and the perceived usefulness are significantly higher in the second use case.

The user expectations showed that the employees in the first use case are much more critical of the implementation of smart glasses as work assistance. Both, a lower expected usefulness and the fear of negative effects in case of operating errors, characterize the results in the first use case. The identified user expectations of the employees in the second use case indicate a higher affinity to technology at the workplace and, as a result, no concerns about the ease of use. One possible explanatory approach, which is also supported by comparing the use cases with each other, is the task-technology fit.

The next step is to continue the evaluation after a first time use of new work assistances in the use cases. For this purpose, the first use case initially was implemented on three different technologies (two models of smart glasses and one tablet). The use of the different technologies as work assistance in the use case will be evaluated soon. It will point out to what extent the expectations coincide with the actual user experience and whether a positive attitude of the employees on the part of the usability and acceptance can be achieved.

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References

[1] Spath D, Ganschar O, Gerlach S, Hämmerle M, Krause T, Schlund S. Produktionsarbeit der Zukunft – Industrie 4.0. Stuttgart: Fraunhofer Verlag, 2013.

[2] Apt W, Bovenschulte M, Hartmann EA, Wischmann S. Foresight-Studie „Digitale Arbeitswelt“. Forschungsbericht 463 für das Bundesministerium für Arbeit und Soziales. Berlin: Institut für Innovation und Technik, 2016.

[3] Windelband L. Zukunft der Facharbeit im Zeitalter „Industrie 4.0“. Journal of Technical Education. 2014; 2(2):138-160.

[4] Terhoeven J, Wischniewski S. How to Evaluate the Usability of Smart Devices as Conceivable Work Assistance: A Systematic Review. In: Schlick CM, Duckwitz S, Flemisch F, Frenz M, Kuz S, Mertens A, Mütze-Niewöhner S, editors. Advances in Ergonomic Design of Systems, Products and Processes. Proceedings of the Annual Meeting of GfA 2016. Berlin Heidelberg: Springer; 2017. p. 261-274.

[5] Park B, Plass JL, Brünken R. Cognitive and affective processes in multimedia learning. Learning and Instruction. 2014; 29:125-127.

[6] De Guinea A, Titah R, Léger PM. Explicit and Implicit Antecedents of Users' Information Systems Behavioral Beliefs: A Neuropsychological Investigation. Journal of Management Information Systems. 2014; 30(4):179-209.

[7] DIN EN ISO 9241-210. Prozess zur Gestaltung gebrauchstauglicher interaktiver Systeme; Deutsche Fassung EN ISO 9241-210. Berlin: Beuth, 2010.

[8] Davis, FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly. 1989; 13(3):319-340.

[9] Grauel BM, Terhoeven JN, Wischniewski S, Kluge A. Erfassung akzeptanzrelevanter Merkmale von Datenbrillen mittels Repertory Grid Technik. Zeitschrift für Arbeitswissenschaft. 2014; 68:250-256.

[10] Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e. V. Zukunft der Consumer Technology. Berlin: Bitkom e. V., 2017.