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- RESEARCH ARTICLE-

An Interface Design Guideline for Augmented Reality Applications on See-Through Head Mounted Displays

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Abstract

Augmented Reality (AR) is a newly-emerging field of research in the last decade as a result of new technological progress, although it has been discussed in the literature conceptually for many years. Nowadays, it is likely to come across AR applications in a wide range of areas such as tourism, education, marketing and advertising, sports, games and entertainment, medical, military, and industry. While AR applications have been developed to operate mostly on mobile devices, now they are being started to develop for transparent, optical head-mounted displays (optical-HMD) such as smart glasses with the advent of wearable technologies. However, scientific studies on designing usable interfaces where smart AR glasses users can easily interact with the application have remained limited. In this study, an AR application was developed for use in maintenance and assembly processes working on smart glasses by using a design criteria checklist that is compiled from the literature. First of all, the experts who know the Human-Computer Interaction (HCI) field evaluated the application interface via the heuristic evaluation method, and they determined the deficiencies of the AR application interface. Afterward, interface components were improved, and interaction methods were updated, and then the AR application was tested on a real assembly problem with potential users. Finally, the confronted usability problems were listed. As a result, the design criteria that should be considered during the development of AR applications that will work on optical-HMD were updated, and an updated design guideline was added to the literature.

Keywords: Augmented Reality, Design Guideline, Human-Computer Interaction (HCI), Usability, Head Mounted Display (HMD).

Introduction

Augmented Reality (AR) is one of the crucial fields of research and application that attention-grabbing in line with the technological developments experienced in recent years. AR, which combines virtual objects with the real world, is used to enrich users' real-world experience. Azuma (1997) defines the AR is an interactive and concurrent reality application that combines the real world with the virtual world in a 3D environment. According to another definition, AR is an emerging technology that enables us to see more than what we see, to hear more than what we hear, to feel more than what we feel, and even to perceive more than the odours we receive (Daponte et al., 2014). Although the AR concept is occasionally confused with Virtual Reality (VR), AR applications are accomplished in the real world rather than in a virtual world. Milgram & Kishino (1994) explained the differences between these two concepts in the reality-virtuality continuum in Figure 1.

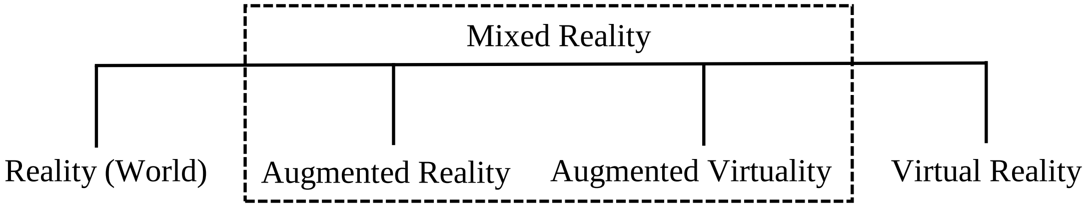

Figure 1. Milgram's reality-virtuality continuum

Human-Computer Interaction (HCI) is a research area that focuses on examining and enhancing the interaction between computer systems and its users. According to the ACM SIGCHI, HCI is a discipline associated with designing, evaluating, and applying usable interfaces to computer systems for end-users (Ariyana & Wuryandari, 2012). International Organization for Standardization (ISO) defines usability as the basis of HCI discipline, as the interaction of users with the developed software in an effective, efficient, and satisfying manner (ISO, 1998). However, the developed applications are not always useable due to the inability to design the interfaces that will enable effective, efficient, and satisfactory interaction between AR technologies and end-users. Besides, the developed software must be evaluated in detail based on many usability criteria, for an interface to be usable. There are many different design criteria in the HCI literature for assessing the usability of the designed software. These design criteria still reflect the authors' opinion, and they have been suggested based on the technologies of their periods. Besides, the recommended design criteria for AR applications are limited, and they are mostly specific to mobile technologies such as phones, tablets, etc. It is thought that the usability of AR glasses application interfaces cannot be evaluated with the design criteria in the literature despite the number of AR applications developed with the widespread use of AR glasses has started to increase in recent years (Dünser et al., 2007; Dünser & Billinghurst, 2011; Dima, 2013; Ko et al., 2013; Endsley et al., 2017; Stanney et al., 2003; Atkinson et al., 2007). For example, even Nielsen's Heuristics, which is the most commonly known and used interface design principles, do not cover the placement, selection, and manipulation procedures of virtual objects in 3D space (Dünser & Billinghurst, 2011).

In this study, an interface design guideline was proposed to evaluate the usability of AR application is running on Head-Mounted Display (HMD) devices that will be a part of our life in the future. In the first phase, the interface design criteria (heuristics) included in the HCI literature were examined. The design criteria that could be used in the development of AR applications for HMD devices were compiled. Secondly, the design criteria, which were mentioned in different studies but were similar to each other, were rewritten and grouped. Then, an AR application was developed, and the application interface was tested using both expert-based and user-based usability tests. Finally, based on our test results, and interface design guideline has been proposed for use in usability evaluation of AR applications which is running on optical-HMD devices.

Material and Methods

Head-Mounted Displays

AR applications can be implemented on almost any technological device, but different AR applications especially run on computers, mobile devices, head-mounted displays (HMD), and projection devices. However, augmenting the real-world perception and providing its continuity depends on the AR technology used substantially. HMD devices, which enable direct interaction with the real world, will be AR technologies of the future instead of hand-held devices such as mobile phones and tablets. It has been emphasized in many studies that HMDs are more useful than hand-held devices, monitors, and screens, and also, this technology will become much more preferable (Wu et al., 2016; Fangyang et al., 2010). In HMD systems, two different imaging technologies have been using that are called as optical see-through and video see-through (Azuma et al., 2001). Although there are HMD devices using projection systems, they are not widely used. Many studies reveal that optical-HMD systems offer more advantages in AR applications (Henderson & Feiner, 2011; Rentzos, 2013). Therefore, Epson Moverio BT-300 AR glasses, an optical-HMD device, were used in this study (Figure 2).

Figure 2. Epson Moverio BT-300 AR Glasses

Development of AR Application

Many interrelated parameters should be taken into consideration to design the interface in AR applications appropriately. After the determination of imaging technology, 2D/3D virtual contents, tracking type, interaction method, application area, and target audience designate the details of interface design. In this study, an AR assembly application has been developed, which shows how to install the hardware components of a desktop computer, running on Epson Moverio BT-300 AR glasses with optical-HMD imaging technology. The target audience is inexperienced computer users who have never install even a single hardware component into a chassis.

The proper augmentation of reality depends on perceiving the real-world correctly. For this reason, the tracking methods that determine where and how virtual contents will be formed in the real world are among the most discussed subjects in AR research. Tracking methods are divided into two groups as "sensor-based" where sensors such as GPS, Gyroscope, pressure, altitude, etc. are used and "vision-based" where video cameras are used. Also, visual-based tracking methods are divided into two groups as “marker-based” and “markerless” (Bozyer, 2019). Since it is impossible to place a marker in the computer case, a markerless tracking method was used in this study. To perceive the computer case where the hardware components will be installed, from different points of view and under different lighting conditions correctly, a model-based tracking method that enables tracking by using together with the 3D CAD model and media image of an object was used.

The interaction with virtual objects in the real world can be established by using Epson Moverio BT-300's touchpad device. However, users have to use their hands to complete assembly works. Thanks to the Google Cloud Speech API, voice commands' interaction with the interface has been established because of the necessity of handsfree interaction. Images were supported with animations and audio narration to describe the assembly process appropriately since the installation procedures were complex, and the virtual contents to be used in AR applications were 3D. It was proven that 3D digital virtual contents gave much better results in assembly applications than 2D or 3D virtual contents in the form of the wireframe (Blattgerste et al., 2018). After the details to be used in the interface design were determined, the interface of the software to be tested (Figure 3) was developed with Epson AR SDK and Unity 3D providing easy integration of 3D contents.

Figure 3. The image of user interface taken from the right side of Moverio BT-300

Design Guideline for optical-HMD’s and Usability Tests

At this stage, firstly, the universal design criteria (heuristics) mentioned in the literature and the design guidelines proposed for mixed reality (AR&VR) were analyzed, and a new design guideline was created for the evaluation of AR applications that running on optical-HMD devices (Table 1). Afterwards, the AR application developed and called Assembly+ was evaluated with our new design guideline by five different HCI field experts, and the application interface was improved with the feedback received from the experts. Following this, the performance of the Assembly + application was measured by user experiments with eighteen different users who are inexperienced in the Assembly of computer hardware components. The number of experts and participants involved in the usability tests was determined based on the study conducted by Nielsen (1992). Six different assembly tasks were given to inexperienced users, a camera was set up to see the test site, and user tests were recorded. The demographic data of the users and their opinions about the application interface were collected through questionnaire forms. The usability questionnaire form was developed based on the PSSUQ (The Post-Study System Usability Questionnaire) developed by Lewis (1995) and USEQ usability evaluation questionnaires designed by Lund (2001). However, there are no questions regarding the evaluation of AR interfaces in the survey forms mentioned above. So, new items were added to the questionnaire to evaluate the usability of the AR interfaces considering the studies in the literature. Furthermore, optional explanation fields were added under each question to receive the opinions and suggestions of users about their experiences. The NASA-TLX evaluation form was used to calculate the user's cognitive load arising from the AR interface (Hart & Staveland, 1988).

Table 1. Interface Design Guideline for optical-Head Mounted Displays

Design Criteria (Heuristics)			**Source**
1. Ease of Learning and Ease of Use (LU)			
LU-1	Consistent Design and Software Standards	The interface should include standard software components that users are facing every day.	Nielsen, 1994; Dünser et al., 2007; Ko et al.,2013; Atkinson et al., 2007
LU-2	Interaction Diversity	Different interaction methods should be included to design because of the purpose of using an AR software may vary.	Nielsen,1994; Dünser et al., 2007; Ko et al.,2013; Endsley et al., 2017; Atkinson et al., 2007; Ganapathy, 2013; Rentsoz et al., 2013; **Usability Tests**
LU-3	User Control and Freedom	Users should feel that they have complete control over the system. If necessary, users should be able to repeat the last operations they perform efficiently.	Ko et al., 2013; Atkinson et al., 2007; Nielsen, 1994; **Usability Tests**
LU-4	Preventing and Correcting Errors	The interface should be designed to prevent errors from occurring. If errors occur, the system should alert the user and show how to fix them.	Nielsen, 1994; Dünser et al., 2007; Ko et al., 2013; Atkinson et al., 2007; Ganapathy, 2013
LU-5	Help and Support	Help should be included in the design since users may need information about the system's operation.	Nielsen,1994; Ko et al.,2013; Atkinson et al., 2007; **Usability Tests**
LU-6	Dynamic Feedback	The interface should notify users of the system's current status continuously. Users should be able to see the result of the commands immediately. **Haptic interactions should be included in the design.**	Azuma, 2001; Nielsen, 1994; Dünser et al., 2007; Ko et al., 2013; Endsley et al., 2017; Atkinson et al., 2007; Ganapathy, 2013; **Usability Tests**
LU-7	**Specifying AR Screen Limits**	**The limits of the screens built into AR glasses to show virtual objects should be specified so that users do not search virtual objects beyond the borders.**	**Usability Tests**
2. Interface Design & Interaction (DI)			
DI-0	*Minimal Physical Load*	*The application interface should be designed so that tasks can be completed in a few steps. Also, the application should not involve the tasks that would force the users, tire them and cause health problems.*	*Dünser et al., 2007; Ko et al.,2013*
DI-1	Minimalist Visual Design	The presentation of information should be as simple as possible, and the interface component density should be reduced by grouping similar ones and gathering them under a menu. Also, the interface components must be positioned on the AR device so as not to interfere with seeing the real world. **Interface components and virtual objects should only appear when necessary.**	Azuma, 2001; Atkinson et al., 2007; Nielsen, 1994; Ganapathy, 2013; **Usability Tests**
DI-2	Minimal Cognitive Load	The system should be simple to use, the tasks should be presented to the users step by step, and thus the mental load should be minimized.	Azuma, 2001; Nielsen, 1994; Dünser et al., 2007; Endsley et al., 2017; Ko et al., 2013; Atkinson et al., 2007; Ganapathy, 2013; **Usability Tests**

DI-3	Interface-Environment Harmony	While designing the interface, the properties of AR systems such as dynamism and space independence should be considered. The interface should be designed considering that environmental conditions can change such as contrast, color, brightness and item size.	Azuma, 2001; Ko et al., 2013; Endsley et al., 2017; Atkinson et al., 2007; Ganapathy, 2013; Rentsoz et al., 2013
DI-4	Adaptation to the real-world and Metaphors	Interface components should be compatible with the real world. The software should speak the user's language, and the interaction methods and metaphors used in the real world should be used to interact with the system.	Azuma, 2001; Ko et al., 2013; Endsley et al., 2017; Atkinson et al., 2007
DI-5	Hardware-Software Compatibility	AR hardware must be able to meet the requirements of the AR software to be designed. For example, a 4K camera or a GPS module should be ready when the high-resolution real-world image or the geographical location information is needed.	Dünser et al.,2007; Endsley et al., 2017; Atkinson et al., 2007; **Usability Tests**
3. Ergonomics and Comfort (EC)			
EC-1	Mobility	AR device must be portable to benefit from dynamic AR applications at the highest level.	Rentsoz et al., 2013; **Usability Tests**
EC-2	Ergonomic Design and Personalization	AR devices should have an ergonomic design. Users should be able to customize the AR devices (such as HMDs' nose grips) according to their needs.	Azuma, 2001; Ko et al., 2013; Endsley et al., 2017; Rentsoz et al., 2013; **Usability Tests**
EC-3	User Satisfaction	The designed interface should entertain the user and be equipped with satisfying virtual content. **The application interface should be gamified and evoke a constant sense of accomplishment.**	Dünser et al.,2007; Ko et al.,2013; **Usability Tests**
EC-4	User Health and Safety	Both the AR device and the application interface should not threaten the user's health and safety and should be designed so as not to cause physical or mental damage to the user. The usage time of the AR device should be limited according to the characteristics of the AR technology used.	Rentsoz et al., 2013; **Usability Tests**
4. Augmented Reality and Virtual Objects (AR)			
AR-1	Presentation of Virtual Objects	Virtual objects should be presented in a way that does not block other objects or real-world experience. Adequate virtual objects should be presented at the same time, and the intended use of them should be explicit.	Azuma,2001; Ko et al.,2013; Endsley et al., 2017; Ganapathy, 2013; Rentsoz et al., 2013; **Usability Tests**
AR-2	Visibility of Virtual Objects	The virtual objects should be in harmony with the real environment, and the features such as the color, size, contrast and resolution of the objects should be sufficient for visibility.	Azuma,2001; Dünser et al.,2007; Ko et al.,2013; Endsley et al., 2017; Ganapathy, 2013; Rentsoz et al., 2013
AR-3	Robustness of Virtual Objects	Virtual objects should be easy to follow in the real world. Problems such as tremors and disappearance should be reduced as much as possible. Virtual objects should be adjusted automatically according to the movement and perspective of the user.	Azuma,2001; Ko et al.,2013; Endsley et al., 2017; Rentsoz et al., 2013; **Usability Tests**
AR-4	Real World Relationship with Virtual Objects	The virtual objects used on the interface must be natural and real-like and interact dynamically with other objects. Each virtual object must be presented following the physics rules considering the details such as distance, angle, position, etc.	Azuma,2001; Rentsoz et al., 2013; Ganapathy, 2013; **Usability Tests**

Results and Discussion

Assembly+ was evaluated with the heuristic evaluation method independently by five HCI specialists by using the interface design guideline compiled from the literature in the first section of the study. The problems detected after the heuristic evaluation were discussed in the meeting where the experts participated, and the required improvements were determined to make the designed software more usable. Placing voice instructions by removing the text boxes explaining how to perform the assembly tasks since they make the viewing of virtual and real objects difficult, performing the interaction with the interface with voice instructions rather than touchpad device of Epson Moverio BT-300, replacing virtual images of hardware components with 3D models and indicating the boundaries of the screen where the virtual contents have appeared are some of these improvements. All of the improvements are given in Table 2.

As seen in Table 2, in the first version of the Assembly+, the interaction was only performed with the touchpad device and the boundaries of the screen where the virtual objects occurred were not specified. Moreover, the details of the assembly tasks to be performed were conveyed with a text box, and the hardware components were represented with simple geometric figures. The improvements except for the 6th item were fully implemented in the second version of the Assembly+. In the sixth item, although it was desired to strengthen the help menu of the AR application with the videos showing the assembly details of the hardware components to the users, due to some technical restrictions, only pictures were included in the help menu. In order to provide handsfree interaction, voice commands were developed for each task, sub-steps of the tasks, going to the next or previous list, asking for help and listening to the information one more time.

Table 2. Improvements to be committed in AR software

No	Improvements
1	Development of voice commands to establish voice interaction
2	Specifying the screen boundaries in which virtual objects appear in smart glasses
3	Removing text boxes
4	Improving AR software to reduce shift and loss of images
5	Dividing the task of attaching cables to the computer case (task 6) into more sub-steps
6	Developing the help menu with virtural objects such as videos, images, drawings, etc..
7	Organizing the steps of tasks hierarchically
8	Preventing the beginning a new task without completing the present one
9	Replacing virtual objects representing hardware components with real 3D models
10	Adding controls to abort tasks and exit the application

Following the improvements performed on the Assembly + interface, user tests were carried out with inexperienced users to measure performance, and the whole process was recorded. Then, each participant was asked to fill out the usability surveys where the AR interface was evaluated and the NASA-TLX survey where the cognitive load created by the interface was detected. The 7-point Likert scale, where scores between -3 and 3 are given, was used in the usability surveys. According to the answers given to survey questions, the details regarding the answers whose average value is below “2” are given in Table 3. Besides, as a result of the NASA-TLX survey, it was determined that the cognitive load created by the interface on 18 participants distributed between 15.0 and 49.2 on the 0-100 scale, and the mean cognitive load was 31.4. This value indicates that the Assembly+ interface is easy and understandable, and it does not force users cognitively. It is possible to decrease the cognitive load further if the problems stated in the open-ended comment areas (Table 4) under the survey questions are solved.

Table 3. Usability assessment questions with an average value below “2”.

Questions		-3	-2	-1	0	1	2	3	Avg.
Q5.	I can assembly computer hardware without support	0	0	0	2	3	8	5	1,9
Q11.	It was easy to use and control the system	0	0	0	2	5	5	6	1,8
Q27.	Virtual AR images and shapes were easily noticeable	0	0	0	2	4	7	5	1,8
Q28.	Virtual objects were reflected on the screen quickly enough without waiting	0	0	1	2	3	7	5	1,7
Q32.	Virtual objects on the screen were stable, not disappearing	0	0	2	2	9	4	1	1,0
Q34.	The AG glasses had an ergonomic design and were easy to use	1	1	1	2	4	3	6	1,2

According to Table 3, when the distribution of the questions regarding the title of "ease of learning and remembering," which covers the first five questions of the survey, is examined, it is seen that there is no deviation in the answers except for the fifth question. Moreover, two of the study participants stated that they were not sure whether they could perform the same tasks again without support after the assembly activities that they performed with AR glasses and Assembly + application. It is not always easy for users to use and control the system according to the answers given to the 11th question from the questions under the title “Interface design and ease of use.” At this stage, the participants stated that they had problems in correcting errors, following the voice instructions and viewing the virtual 3D images. It is seen that there are more negative opinions in the answers of 26th-35th questions under the heading “Augmented reality technology and use.” This situation indicates that the participants had problems interacting with the interface components and virtual objects during the use of the software. Especially the disappearance of 3D figures and the difficulty of making them visible again caused the users to declare negative opinions.

However, it should be underlined that the design of the Moverio BT-300 AR glasses used in the study affects the user experience. It was observed that especially female users experienced problems since the device did not adequately fit on their heads while using the glasses. Also, Epson eliminated this design problem in its new generation BT-350 AR glasses. The issues stated by the participants and given in Table 4 also support this situation. The participants mostly experienced difficulties due to the disappearance of virtual objects, invisibility of virtual objects, coincidence of voice instructions, lack of perception of voice commands and issues related to the ergonomic design of the AR glasses.

Table 4. Problems and suggestions stated by the users on the surveys

Problems and suggestions	**Users Identifying the Problem**	**Freq.**	**Suggestions of Users**
Virtual objects were blurred.	5	1	
Virtual images have shifted, slipped from their first position.	2, 3, 9	3	
Sometimes virtual objects disappeared.	2, 3, 4, 6, 8, 10, 11, 12, 13, 15, 16, 18	12	
It is not easy to see or find virtual objects.	1, 5, 11, 13, 15, 16, 17	7	
The display where virtual objects appear is narrow.	3, 6, 7, 10, 11, 14	6	The screen of the smart glasses should be wide
Voice prompts sometimes overlap.	1, 2, 3, 7, 8, 12, 13, 18	8	
Voice guidance does not contain enough information.	18	1	More detailed information should be given
Some information is repeated frequently in voice guidance.	8, 11	2	Information on how to use the software should not be included in every step
The system does not detect commands for voice interaction or it detects late.	1, 2, 3, 4, 5, 6, 8, 9, 17	9	
AR glasses are not ergonomic.	2, 3, 5, 8, 9, 10, 14, 15, 16, 18	10	AR glasses should be adjusted according to the user
AR glasses caused eye strain.	16, 18	2	
AR glasses caused headaches.	10, 15	2	
The visuals presented in the help menu are insufficient.	1, 3, 4, 15, 16	5	Videos should be added to the help menu
It is not easy to see the pictures presented in the help menu.	2, 4, 8, 9, 15	5	Contrast and transparency should be adjusted to the real world
The number of steps is more than it should be, the tasks are divided into many sub-steps.	7, 8	2	Screwing steps should be combined with previous steps
Animations provided with virtual objects are insufficient.	15	1	The amount of virtual content should be increased
It is not easy to get used to the system.	17	1	

The user experiments were recorded with a camera, and then these records were examined to determine the participants' performance data. These data are how many errors were made during the mounting process, how many times the help menu was used, how long the voice instructions have listened and the total task completion times. In Table 5, where the performance data are given, it is seen that the completion time of the mounting process varies between 493 and 820 seconds, and the success rate varies between 82.4% and 100%. The mean success rate of the participants in the assembly tasks was detected as 94.4%, while the mean completion time was 667.5 seconds. However, the time spent screwing the components into the case was not included in the total task completion time since the hand skill may vary from person to person. The time calculated in the screwing steps was evaluated as determining the place to be screwed, taking the screw and carrying it to the computer case after listening to the voice instructions.

Table 5. Performance data of the test participants/users

	U1	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**
Total Completion Time (sec)	557	723	687	736	755	638	616	523	722
Success Rate	100,0%	82,4%	82,4%	100,0%	88,2%	100,0%	94,1%	100,0%	88,2%
Incorrect Trial	4	3	6	1	2	0	1	1	3
Request for Help	2	3	3	4	1	2	2	1	3
Request for Information Playback	0	5	6	7	5	2	5	4	6
	U10	**U11**	**U12**	**U13**	**U14**	**U15**	**U16**	**U17**	**U18**
Total Completion Time (sec)	618	493	503	728	779	820	785	813	519
Success Rate	100,0%	100,0%	94,1%	100,0%	100,0%	88,2%	94,1%	88,2%	100,0%
Incorrect Trial	2	3	3	4	2	2	3	3	1
Request for Help	1	2	1	2	3	7	5	3	1
Request for Information Playback	3	1	3	1	3	4	5	7	4

Another significant result obtained in the study is that the steps of installing the power supply component and power cables, which are the last of the assembly tasks, took an average of 416.4 seconds. This value forms approximately 62% of the total mean assembly time. In other words, the participants had difficulty in the last assembly task, where virtual objects were the most difficult to make visible. This situation shows that the real world that is augmented with virtual 3D models and animations how will be useful. On the other hand, the mean number of incorrect assembly trials of the participants is 2.4. During each user experiment, the participants demanded help on an average of 2.6 times and listened to voice instructions on an average of 3.9 times. When it is considered that there are 23 different voice instructions in the software designed for the test, it is seen that approximately 4/23 voice instructions were listened to again in each experiment. As a result of the experiments, all these data were evaluated together, and the interface design guidelines given in Table 1 were updated in the light of the obtained results.

Conclusion

In this study, an interface design guideline to be used in the development of the AR applications that are running on optical-HMD AR glasses were proposed. Each criterion of the proposed guideline was compiled from the studies in the literature, and these were updated by the data and findings obtained from user experiments. The used references for each design criteria, and the newly added criteria and their explanations, the checked current criteria and the criteria removed from the list are stated in Table 1. The new heuristic criteria and added explanations are emphasized in bold, and the removed heuristic criteria are specified in italics. “DI-0. The minimal Physical Load” heuristic was removed from the final design guideline since the “EC-4. User Health and Safety” heuristic included the mission of reducing physical damage to users. The results obtained from the usability tests performed within the study's scope reveal that the developed user interface for AR application, based on the suggested heuristics, is thriving. However, the proposed interface design criteria for AR should be verified by conducting further studies with different optical-HMD devices and different AR applications on various platforms.

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