ISSN: 0974-5823 Vol. 7 No. 2 February, 2022

International Journal of Mechanical Engineering

A study on usability based on color difference between UI and mixed reality environment

Yujin Choi[1] and Yoon Sang Kim[2]

[1]BioComputing Lab, Department of Computer Science and Engineering, Korea University of Technology and Education (KOREATECH), Cheonan, Republic of Korea

[2]BioComputing Lab, Institute for Bio-engineering Application Technology, Department of Computer Science and Engineering, Korea University of Technology and Education (KOREATECH), Cheonan, Republic of Korea

Abstract - As people begin to notice mixed reality, various studies on usability in mixed reality(MR) have been conducted. User interface(UI) is one of the representative factors that affect usability in MR. In conventional platforms such as mobile devices and personal computers, various studies have been conducted on providing adaptive UI, and recently, such studies are also conducted in MR environments.

In adaptive UI, color is one of the factors that can be provided adaptively. These UI color is a main factor that can affect usability for an application. Conventional studies on UI color mainly focused on effect of color or provision of personalized color. However, studies analyzing the effect of UI color in consideration of the characteristics of MR that can have various environments are insufficient.

Therefore, in this paper, we study the usability based on color difference between UI and MR environment. For this, experiments using similar color UI and complementary one were conducted and the results were analyzed quantitatively as well as qualitatively. As a result of the experiment, shorter total task time($p=0.042$) and shorter object searching time($p=0.005$) were achieved in complementary color UI than the one in similar color UI.

Index Terms - Mixed Reality, User Interface, Color, Usability.

INTRODUCTION

Recently, attempts to convert conventional face-to-face activities to non-face-to-face activities are increasing because various face-to-face activities have been reduced or suspended due to COVID-19 [1-3]. However, non-face-to-face activities inevitably provide a relatively low sense of immersion compared to face-to-face activities, and it became the limitation of non-face-to-face activities [4-6]. To overcome this, research to apply mixed reality(MR) to non-face-to-face activities has recently been conducted [7, 8].

One of the representative factors that can affect the usability in mixed reality is the user interface(UI) [9-11]. In conventional platforms such as mobile devices and PCs, research has been conducted to adaptively provide UI to improve usability [12-15], and recently, research like this has also been conducted in MR [16-18].

In adaptive UI, color is one of the factors that can be provided adaptively. UI color is one of the main factors that can affect the usability for application [19-21]. However, conventional studies on UI color mainly focused on effect of color or provision of personalized color and studies analyzing the effect of UI color in consideration of the characteristics of MR that can have various environment are insufficient.

In this paper, we analyze usability based on color difference between UI and MR environment. To analyze usability, the following steps were performed: 1) experiment conduct, 2) experimental result analysis. First, in experiment conduct step, the subjects conduct the experiment under two different color difference conditions. Second, in experimental result analysis step, usability based on the color difference is analyzed using the quantitative and qualitative factors measured during the experiment. For usability analysis, task time are used as a quantitative factor and a user satisfaction score (likert 5 scale) are used as a qualitative factor.

This paper is composed as follows. In section 2, we introduce related works. In section 3, we conduct an experiment based on color difference between UI and MR environment and analyze the experimental results. Finally, in section 5, we present conclusions and future works.

RELATED WORKS

I. *Usability*

According to the international standard ISO 9241-11, usability is defined as the degree of effectiveness, efficiency, and satisfaction when a user performs a certain task in a specific environment [22] as the followings:

- Effectiveness refers to the extent to which the system contributed to the achievement of the user's purpose, and is evaluated based on the accuracy and completion of the user's task performance [22, 23].
- Efficiency relates to the resources the user puts in to perform the task, and is evaluated as the efficiency of the resource input [22, 23].
- Satisfaction relates to the satisfaction that users feel while using the system, and it is evaluated as the qualitative satisfaction felt while using the system [22, 23].

Recently, studies have been conducted to evaluate MR applications by utilizing such usability [24-26]. Hoppenstedt, B. et al. [24] conducted a study to evaluate the usability of mixed reality for the accomplishment of visual analytic tasks. To evaluate, time, errors, path, angle, stress(Questionnaire), gender and age(Questionnaire), and etcetera were measured. El Ammari, K. et al. [25] conducted a study to evaluate the usability of remote interactive collaboration in facilities management using BIM-based mixed reality. To evaluate, errors, time, and the easiness level, gender and age(questionnaire), overall satisfaction level(questionnaire, using Likert scale) and etcetera were measured. Bolder, A. et al. [26] conducted a study to compare car infotainment system between MR environment and real car environment, and used usability as one of the comparison method. To use usability, time, readability(Questionnaire), visual quality(Questionnaire) and etcetera were measured.

Most of studies showed that quantitative and qualitative factors were measured together for usability evaluation. In this study, among these factors, time was selected as a quantitative factor and user satisfaction was selected as a qualitative factor.

II. UI color

Conventional studies on UI color mainly focused on effect of color[19] or provision of personalized color in adaptive UI[20, 21]. Hawlitschek, F. et al. [19] conducted a study on the trust given by UI color based on NeuroIS theory, and confirmed that the perceived warmth was higher when users sensed red compared to blue. Yigitbas, E. et al.[20] focused on framework for providing adaptive UI, and proposed a CoBAUI framework that includes the action of changing font color according to brightness. Yigitbas, E. et al. [21] focused on adaptive UI in mobile environment, proposed an adaptive UI that includes the action of changing the UI color according to the brightness, and applied the proposed adaptive UI to the Android mail application.

Characteristics of MR that used in various environment was not considered in above conventional studies In MR, the background which the UI is displayed are various depending on where the user uses the mixed reality application. Also, even if the location is fixed, the background can be changed significantly by a small movement of the user (e.g. rotation of the head). That is, a UI that has high usability under certain conditions can have low usability under other conditions. Therefore, it is required to conduct a study on UI color considering these characteristics of MR.

EXPERIMENTAL RESULTS AND DISCUSSION

I. Environment

We implemented an MR application for analyzing the usability based on color difference between MR environment and UI. The implemented application provided a function to interaction with virtual object based on hand gestures. Experimental environment using implemented application is shown in Figure 1.

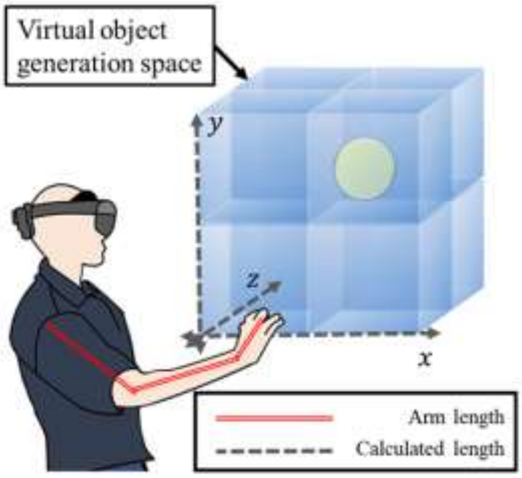

Figure 1. Experimental environment

In Figure 1, blue cubes expressed the virtual object generation space set from the calculated length(gray dashed line in Figure 1), which is based on the measured arm length(red double line in Figure 1). To minimize the influence of body differences in each subject by providing personalized limitation space, virtual object generation space was implemented in same method as [27]. In order to prevent the subjects from adapting to the experiment, virtual objects were randomly generated at positions represented by blue cubes in Figure 1. That is, virtual objects can occur randomly in a total of 8 positions(left-top-front, left-top-back, left-bottom-front, left-bottom-back, right-top-front, right-top-back, right-bottom-front, right-bottom-back), Figure 1 is an example of virtual object is generated in the right-top-front position of cube.

Since this is an experiment about UI colors, even a small difference in the surrounding environment can affect seriously on the experimental results. Therefore, we placed an artificial lighting in experimental environment, to maintain average illuminance(140 lux).

The MR environment in this study means the surrounding environment in real world in which the user uses the MR application, and it can be viewed as an image input through the camera of the MR device. That is, the color difference between the MR environment and the UI is defined as the color difference between the input image of camera in MR device and the color of the UI provided by the MR application. The purpose of this study is to analyze the usability based on the color difference, and for this purpose, two types of UI are used in the experiment as shown in Figure 2. A complementary color UI (Figure 2 (a)) is provided to test the case which the color difference is high between MR environment and UI, whereas a similar color UI (Figure 2 (b)) is provided to test the case which the one is low between MR environment and UI.

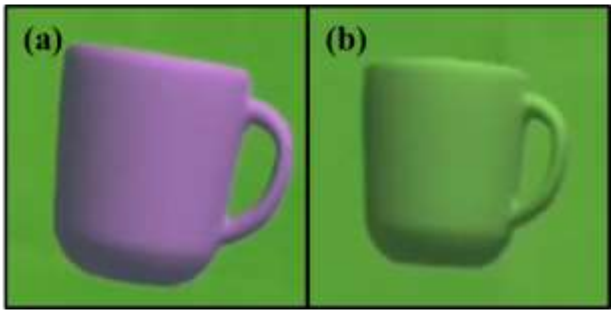

Figure 2. UI types for experiment: (a) Complementary color U, (b) Similar color UI

II. Methodology

For the experiment, 8 subjects in their twenties [28] were recruited, and it was recommended that each subject take a rest before participating in the experiment. We informed the subjects sufficiently about the experiment procedure, and after the explanation, all subjects filled out the experimental consent form.

In the experimental procedure demographic questionnaire, arm length of subject, task information, and user satisfaction were measured. Before the experiment, demographic questionnaire including age, gender, and etcetera was asked and arm length of subject was measured. Measured arm length was used to set the virtual object generation space as shown in Figure 1. After that, the subjects moved to the guided experimental space, and wore the Microsoft Hololens 2 [29] in a sitting position.

In the experiment, tasks to select a target object generated in random position was given to each subject. 1 task was composed of 4 times interactions(selecting) with virtual objects. Subjects were guided to perform the task 6 times per UI type, thus 1 subject was assigned a total of 24 times of interaction attempts per UI type.

During the experiment, task information such as task start moment, interaction start moment and interaction completion moment were measured. Task information were measured to quantitatively evaluate usability based on color difference, and it was measured as shown in Figure 3.

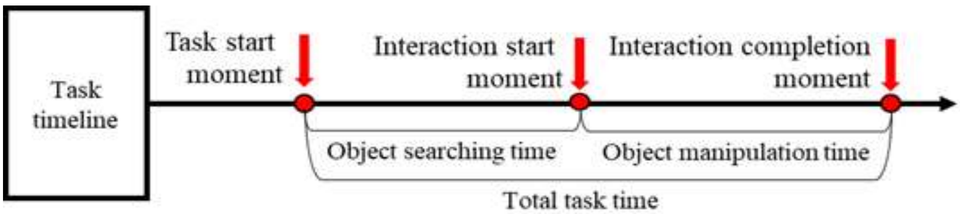

Figure 3. Task information of subjects

The red circles in Figure 3 indicate the task start moment, interaction start moment and interaction completion moment, respectively. When the target object was generated, the task start moment was measured(first red circle in Figure 3). And, when the subject started manipulating the object, the interaction start moment was measured(second red circle in Figure 3). Finally, when the subject finished manipulating the object, the interaction completion moment was measured(third red circle in Figure 3), which is same as the task completion moment.

Object searching time was calculated from the task start moment and the interaction start moment. And the Object manipulation time was calculated from the interaction start moment and the interaction completion moment. Finally, the total task time was calculated from the task start moment and the interaction completion moment.

Whenever subjects completed one task(after the measurement of interaction completion moment in Figure 3), they were asked to enter their user satisfaction with the task. User satisfaction was measured to qualitatively evaluate usability based on color difference, and it was measured on a Likert 5 scale from 1 to 5.

All of the above research procedures were conducted according to the guidelines of the Declaration of Helsinki. In addition, we obtained approval by the Institutional Review Board of KOREATECH in advance for all of the above research procedures (approval on May 26, 2021).

III. Results and discussion

Task time

In this study, task time was used as a quantitative factor to analyze the usability based on the color difference between the mixed reality environment and UI. Task time consists of total task time, object searching time, and object manipulation time, and the total task time is equal to the sum of the object search time and object manipulation time.

The task time measured through the experiment is shown in Figure 4-Figure 6.

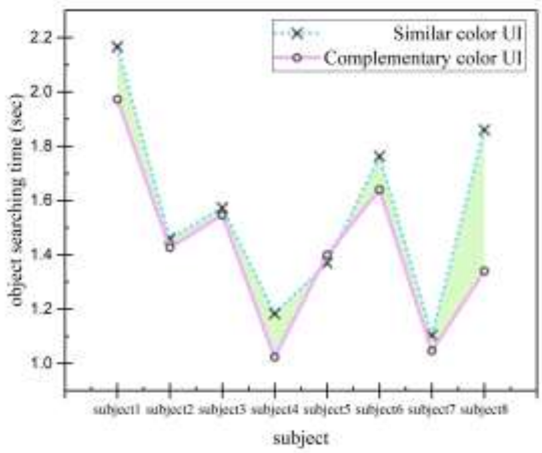

Figure 4. Average object searching time for each subject

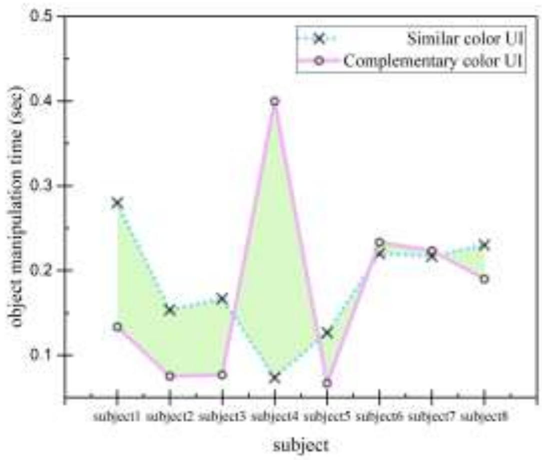

Figure 5. Average object manipulation time for each subject

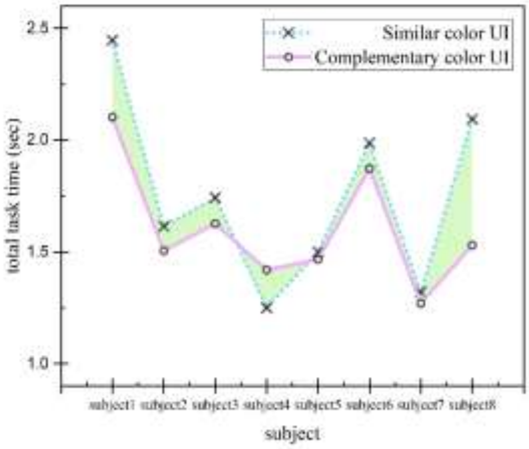

Figure 6. Average total task time for each subject

In Figure 4-Figure 6, green area shows that the difference in task time based on UI color difference. In order to confirm whether the time difference like green area is significant, Wilcoxon signed rank test was performed, which is one of the non-parametric test. The result of the test is shown in Table 1.

Table 1. Results of Wilcoxon signed rank test: task time

	Object searching time CCUI[1]-SCUI[2]	**Object manipulation time** CCUI[1]-SCUI[2]	**Total task time** CCUI[1]-SCUI[2]
Z	-2.829[3]	-.213[3]	-2.029[3]
Asymp. Sig. (2-tailed)	.005	.831	.042

[1] Complementary Color UI [2] Similar Color UI [3] Based on positive ranks

As shown in Table 1, the significance level of the object searching time and total task time were lower than 0.05(red boxes in Table 1). Based on this, it was confirmed that the object searching time was reduced when the complementary color UI was provided(1.4096 sec) compared to the similar color UI was provided(1.5458 sec). Also, it was confirmed that total task time was reduced when the complementary color UI was provided(1.5842 sec) compared to the similar color UI was provided(1.7283 sec). However, in the case of object manipulation time, this difference was not significant, and it is predicted that this is because the interaction in this experiment was a relatively simple interaction called selection.

IV. User satisfaction

In this study, user satisfaction was used as a qualitative factor to analyze the usability based on the color difference between the mixed reality environment and UI. The user satisfaction measured through the experiment is shown in Figure 7.

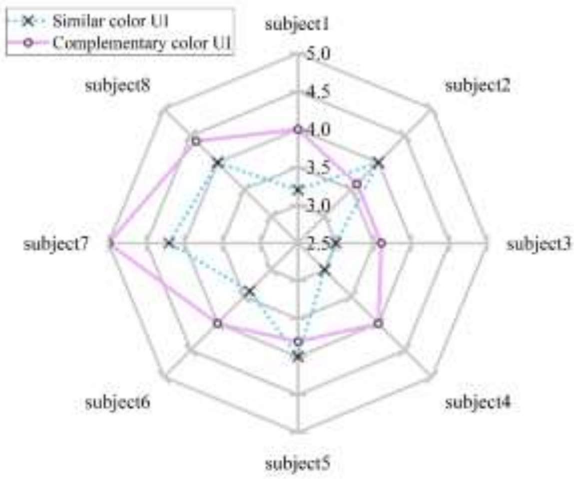

Figure 7. Average user satisfaction for each subject

As shown in Figure 7, it was confirmed that overall user satisfaction was higher when complementary color UI was provided. In order to confirm whether the time difference is significant, Wilcoxon signed rank test was performed, which is one of the non-parametric test. The result of the test is shown in Table 2.

Table 2. Results of Wilcoxon signed rank test: user satisfaction

	User satisfaction CCUI[1]-SCUI[2]
Z	-2.203[3]
Asymp. Sig. (2-tailed)	.028

[1] Complementary Color UI [2] Similar Color UI [3] Based on negative ranks

As shown in Table 2, the significance level of the user satisfaction was lower than 0.05(red box in Table 2). Based on this, it was confirmed that the user satisfaction was increased when the complementary color UI was provided(4.089) compared to the similar color UI was provided(3.644).

CONCLUSION AND FUTURE WORKS

In this paper, we analyzed usability based on color difference between UI and MR environment. For the analysis, we implemented an application providing complementary color UI and similar color UI, and conducted an experiment using the application to measure the factors to analyze the usability of each UI type. For the experiment, the subject wore Hololens2[29] and performed interaction with virtual object. During the experiment, task start moment, interaction start moment and the interaction completion moment, and user satisfaction(likert 5 scale) were measured, and through these values, usability based on UI color was compared. As a result of the experiment, object searching time and total task time, which are quantitative factor, were reduced by 8.81% and 8.33%, respectively, when complementary color UI was provided(1.4096 sec, 1.5842 sec) compared to when similar color UI was provided(1.5458 sec, 1.7283 sec). In addition, user satisfaction, which is qualitative factor, was increased by 12.21%, when complementary color UI was provided(4.089) compared to when similar color UI was provided(3.644). From the results, it was confirmed that providing a UI close to the complementary color of the surrounding environment in a MR environment can have a positive effect on usability.

ACKNOWLEDGMENTS

This work was supported by Electronics and Telecommunications Research Institute(ETRI) grant funded by ICT R&D program of MSIT/IITP[2020-0-00537] If you intend to utilize the contents of this report, you must disclose that the research was supported by Electronics and Telecommunications Research Institute(ETRI).

REFERENCES

[1] Boland, B., De Smet, A., Palter, R., & Sanghvi, A. (2020). Reimagining the office and work life after COVID-19.ISO 690

[2] Embrett, M., Liu, R. H., Aubrecht, K., Koval, A., & Lai, J. (2021). Thinking together, working apart: leveraging a community of practice to facilitate productive and meaningful remote collaboration. International Journal of Health Policy and Management, 10(9), 528-533.

[3] Favale, T., Soro, F., Trevisan, M., Drago, I., & Mellia, M. (2020). Campus traffic and e-Learning during COVID-19 pandemic. Computer networks, 176, 107290.

[4] Daft, R. L., & Lengel, R. H. (1983). Information richness. A new approach to managerial behavior and organization design. Texas A and M Univ College Station Coll of Business Administration.

[5] Daft, R. L., & Lengel, R. H. (1986). Organizational information requirements, media richness and structural design. Management science, 32(5), 554-571.

[6] García-Peñalvo, F. J., Corell, A., Abella-García, V., & Grande-de-Prado, M. (2021). Recommendations for mandatory online assessment in higher education during the COVID-19 pandemic. In Radical solutions for education in a crisis context (pp. 85-98). Springer, Singapore.

[7] Wu, W. L., Hsu, Y., Yang, Q. F., & Chen, J. J. (2021). A Spherical Video-Based Immersive Virtual Reality Learning System to Support Landscape Architecture Students' Learning Performance during the COVID-19 Era. Land, 10(6), 561.

[8] Pidel, C., & Ackermann, P. (2020, September). Collaboration in virtual and augmented reality: a systematic overview. In International Conference on Augmented Reality, Virtual Reality and Computer Graphics (pp. 141-156). Springer, Cham.

[9] Munoz, A., Mahiques, X., Solanes, J. E., Marti, A., Gracia, L., & Tornero, J. (2019). Mixed reality-based user interface for quality control inspection of car body surfaces. Journal of Manufacturing Systems, 53, 75-92.

[10] Hamacher, A., Hafeez, J., Csizmazia, R., & Whangbo, T. (2019). Augmented Reality User Interface Evaluation–Performance Measurement of Hololens, Moverio and Mouse Input.

[11] Ejaz, A., Ali, S. A., Ejaz, M. Y., & Siddiqui, F. A. (2019). Graphic user interface design principles for designing augmented reality applications. International Journal of Advanced Computer Science and Applications (IJACSA), 10(2), 209-216.

[12] Machado, E., Singh, D., Cruciani, F., Chen, L., Hanke, S., Salvago, F., ... & Holzinger, A. (2018, March). A conceptual framework for adaptive user interfaces for older adults. In 2018 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops) (pp. 782-787). IEEE.

[13] Deuschel, T. (2018, July). On the Influence of Human Factors in Adaptive User Interface Design. In Adjunct Publication of the 26th Conference on User Modeling, Adaptation and Personalization (pp. 187-190).

[14] Kolekar, S. V., Pai, R. M., & MM, M. P. (2019). Rule based adaptive user interface for adaptive E-learning system. Education and Information Technologies, 24(1), 613-641.

[15] Miraz, M. H., Ali, M., & Excell, P. S. (2021). Adaptive user interfaces and universal usability through plasticity of user interface design. Computer Science Review, 40, 100363.

[16] Jenkins, M., Stone, R., Lajoie, B., Alfonso, D., Rosenblatt, A., Kingsley, C., ... & Kelly, S. (2021, July). Contextually Adaptive Multimodal Mixed Reality Interfaces for Dismounted Operator Teaming with Unmanned System Swarms. In International Conference on Human-Computer Interaction (pp. 431-451). Springer, Cham.

[17] Lindlbauer, D., Feit, A. M., & Hilliges, O. (2019, October). Context-aware online adaptation of mixed reality interfaces. In Proceedings of the 32nd annual ACM symposium on user interface software and technology (pp. 147-160).

[18] Pfeuffer, K., Abdrabou, Y., Esteves, A., Rivu, R., Abdelrahman, Y., Meitner, S., ... & Alt, F. (2021). ARtention: A design space for gaze-adaptive user interfaces in augmented reality. Computers & Graphics, 95, 1-12.

[19] Hawlitschek, F., Jansen, L. E., Lux, E., Teubner, T., & Weinhardt, C. (2016, January). Colors and trust: The influence of user interface design on trust and reciprocity. In 2016 49th Hawaii International Conference on System Sciences (HICSS) (pp. 590-599). IEEE.

[20] Yigitbas, E., Josifovska, K., Jovanovikj, I., Kalinci, F., Anjorin, A., & Engels, G. (2019, June). Component-based development of adaptive user interfaces. In Proceedings of the ACM SIGCHI Symposium on Engineering Interactive Computing Systems (pp. 1-7).

[21] Yigitbas, E., Hottung, A., Rojas, S. M., Anjorin, A., Sauer, S., & Engels, G. (2019). Context-and data-driven satisfaction analysis of user interface adaptations based on instant user feedback. Proceedings of the ACM on Human-Computer Interaction, 3(EICS), 1-20.

[22] International Organization for Standardization. "ISO 9241-11:1998". Available online: https://www.iso.org/standard/63500.html (accessed on February 2022)

[23] Brooke, J. (1996). Sus: a “quick and dirty’usability. Usability evaluation in industry, 189(3).

[24] Hoppenstedt, B., Probst, T., Reichert, M., Schlee, W., Kammerer, K., Spiliopoulou, M., ... & Pryss, R. (2019). Applicability of immersive analytics in mixed reality: Usability study. IEEE Access, 7, 71921-71932.

[25] El Ammari, K., & Hammad, A. (2019). Remote interactive collaboration in facilities management using BIM-based mixed reality. Automation in Construction, 107, 102940.

[26] Bolder, A., Grünvogel, S. M., & Angelescu, E. (2018, November). Comparison of the usability of a car infotainment system in a mixed reality environment and in a real car. In Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology (pp. 1-10).

[27] Choi, Y., Son, W., & Kim, Y. S. (2021). A Study on Interaction Prediction for Reducing Interaction Latency in Remote Mixed Reality Collaboration. Applied Sciences, 11(22), 10693.

[28] Dey, A., Billinghurst, M., Lindeman, R. W., & Swan, J. (2018). A systematic review of 10 years of augmented reality usability studies: 2005 to 2014. Frontiers in Robotics and AI, 5, 37.

[29] Microsoft HoloLens2. Available online: https://www.microsoft.com/en-us/hololens/hardware (accessed on February 2022).