Usability Test of Immersion for Augmented Reality Based Product Design*

Taejin Ha[1], Yoonje Chang[2], and Woontack Woo[1]

[1] GIST U-VR Lab
{tha,wwoo}@gist.ac.kr
[2] GIST CTRC
Gwangju, 500-712, Korea
naugulp@naver.com

Abstract. In this paper, we evaluate the usability of multimodal feedback for enhancing immersion in augmented reality (AR) based product design environments, introduced in the paper [1]. We study what effects occur when providing multi-sensory feedback to users. First of all, we compare design environments between conventional desktop based design environments and AR based design environments which support multimodal feedback. For a usability test for visual feedback, we test the degree of immersion for showing hands which are occluded by augmented virtual objects, and test the suitability of mapping between content and users' input. In sound feedback, also we test the degree of immersion and suitability of mapping between background-sound/effect sound mapping and corresponding events in the scenario. Lastly, as a test for tactile feedback, we evaluate the effect of the physical entity for virtual objects by registering the object to physical tangible objects, and evaluate the degree of immersion for vibration w.r.t events in scenario. Our analyzed results from usability tests and comments could be useful for enhancing immersion in conventional AR based product design as well as AR based learning and teaching contents for edutainment.

Keywords: Usability Test, Product Design, Multi-sensory Feedback, Augmented Reality, HCI.

1 Introduction

In general, we have proposed multi-sensory feedback such as visual/sound/tactile feedback in order to enhance immersion in Human-Computer Interaction research areas. In particular, conventional virtual reality has developed various systems, where 3D displays, 3D sound, Haptic devices and olfactory display devices have been combined. However, in emerging augmented reality research any system providing multi-sensory feedbacks to users for enhancing immersion is rare. Also systematic usability tests have not been conducted to compare the research in virtual reality.

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In this paper, we do usability tests for immersion for augmented reality based product design systems, providing multi-sensory feedback to the users, as introduced in paper [1-2]. Through a usability test, we evaluate how multi-sensory feedback (visual/sound/tactile) can contribute to enhance immersion in AR based product design environments. For the evaluation, we let users experience tasks in scenario, and then provide each visual/sound/tactile feedback to the users. After the test, we do a quantitative test to determine how much each feedback effects immersion, in interaction with virtual objects. We also do a qualitative test using observations of users' behavior and comments from users. These two tests are based on questionnaires for usability tests.

First of all, we compare two design environments: a conventional desktop based product design environment, and an AR based product design environment, which enables multi-sensory feedbacks. We then do a usability test for visual feedback, evaluating the degree of reality by showing occluded hands which hide augmented virtual objects, and test the suitability of visual mapping w.r.t users' inputs. As criteria for sound feedback, we also test immersion and suitability of background-sound/effect-sound mapping w.r.t context in scenario. In a final test for tactile feedback, we evaluate tactile feedback obtained by registrations of virtual objects on physical tangible objects. We also test the degree of immersion w.r.t vibro-tactile feedback according to events of scenario.

This paper is composed of 6 sections. Section 2 explains AR based design environments providing multi-sensory feedback, and section 3 discusses technical implementation of visual/sound/tactile feedbacks. Section 4 proposes the usability test design, and Section 5 shows the results and analysis of the usability tests. Finally we present conclusions in Section 6.

2 AR Based Product Design Environment Providing Multi-sensory Feedback

In this paper, the product design system of AR environments, in terms of realization and interaction of virtual objects, is able to support multi-sensory feedback for enhancing immersion [1-2], as shown in Fig.1. Users wearing a 3D HMD (Head Mounted Display) on their head interact with virtual objects by grasping a tangible object. This tangible object is a mock-up model of a game-phone. Multiple fiducial markers are attached to provide 3D information. A 3D model is overlaid on the whole area of the tangible object. Also, vibro-tactile feedback and sound feedbacks are provided to the users according to the specific event.

A conventional desk-top based product design environment has several advantages, offering various functions and being able to handle accurate operations. However, this requires users to learn the new operations, and it takes time to become accustomed to the new environment. Also one viewpoint is through a monitor and another viewpoint for interaction is through a mouse or a keyboard on a table. In that situation, awkward interaction may occur because these different viewpoints are not collocated.

On the one hand, in an AR based product design environment, viewpoints between virtual objects and user interaction are collocated, so users wearing an HMD can directly touch or observe the virtual models by using their hands. Therefore intuitive and immersive interactions are possible. In [3], the authors proposed a substitutable method, using an expensive clay mockup model in car production process. There is also a system which can create/edit 3D curves and the surface of virtual models in a workbench environment [4]. In [5], the authors suggest AR techniques for function tests in electronic product design.

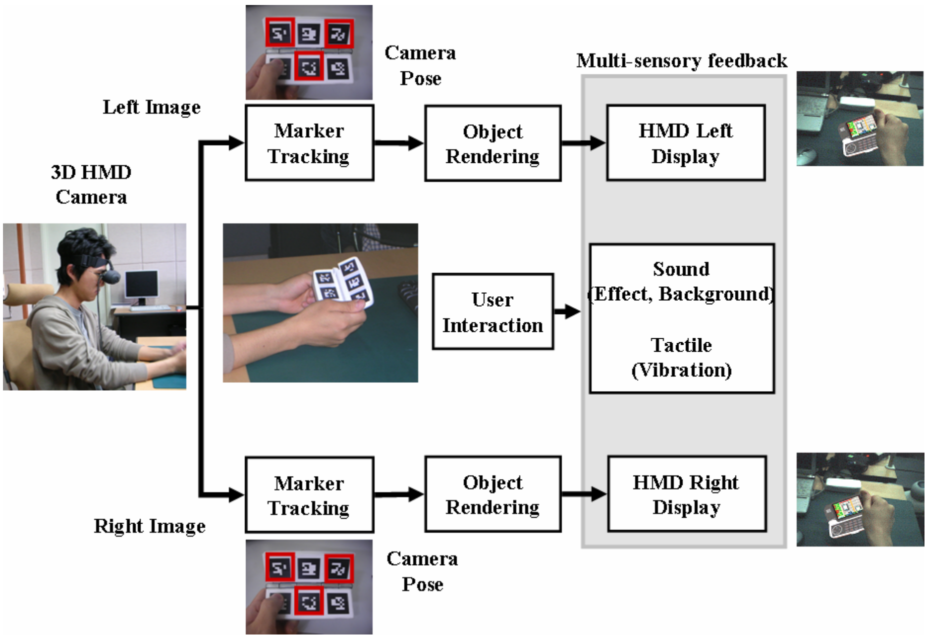


Fig. 1. Overall Procedure

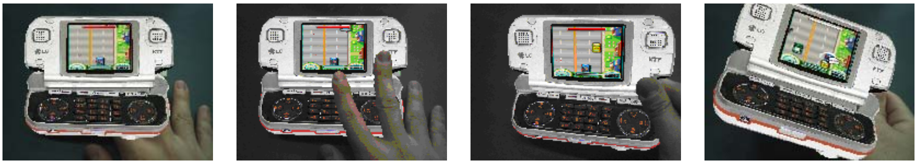
3 Technical Implementations of Visual/Sound/Tactile Feedbacks

In this paper, we select multi-sensory feedback in order to enhance immersion in an AR based product design environment. In this section, we explain the concrete technical implementation for visual/sound/tactile feedback of an AR based product design system.

3.1 Implementation of Visual Feedback

In the AR based product design environment, when users interact with virtual objects using their hands, the hands can sometimes be occluded by the virtual objects, as shown in Fig. 2. (a), because the virtual objects are only a rendering of the image. Paper [1] proposed a method which partially solves the aforementioned problem by overlaying the extracted hand objects of the input image on augmented virtual objects, as shown in Fig 2. (b).

Also, we have considered dynamically responsive content reactive to user input, rather than conventional one-way content. Users can see a racing game displaying an augmented virtual object, and play the game by tilting the tangible object in the direction of up/down/left/right side, as shown in Fig. 2. (c), (d). These directions affect the speed and direction of the car.



(a) (b) (c) (d)

Fig. 2. Implementation of visual feedback (a) Hands occlusion by virtual objects (b) Result for partially reduced hands occlusion problem (c) Tilting a tangible object in the direction of up/down side, have an effect on the speed of a car in racing game. (d) Tilting a tangible object in the direction of left/right side, has an effect on the direction of a car.

3.2 Implementation of Sound Feedback

Most AR techniques have mainly focused on visual feedback. But sound feedback is also important role in immersive interaction. Sound feedback can be present in specific events, and during interaction with augmented virtual objects. In this game-phone scenario, if a car collides with a wall or other cars, then sound effects (e.g. explosion) are played. Also background sound is played by default. Each sound feedback is played asynchronously.

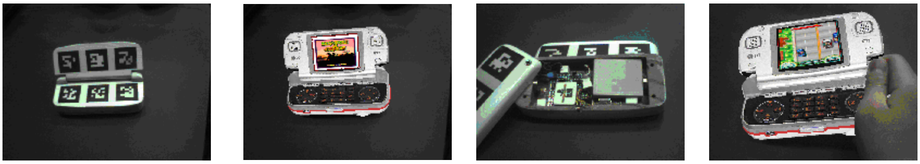
Table 1. Implementation of sound feedback

Situation	Implemented contents
A car is driving along a road	Background-sound (fast beat song)
A car collides with a wall or other cars	Effect sound (explosion sound)

3.3 Implementation of Tactile Feedback

As augmented virtual objects typically do not have a physical entity, users can not touch virtual objects. However, in the paper [1], by exploiting a tangible object (Fig. 3. (a)) the object can have physical properties, so users can touch the virtual objects with their hands. The degree of registration can be enhanced by corresponding scales between a virtual object and a tangible object, as shown in Fig. 3. (b).

Another form of tactile feedback, vibro-tactile feedback, has also been used. Vibration modules (Fig.3. (c)) are embedded in a tangible object. The modules can deliver with appropriate intensity according to the event. Vibration modules can be controlled at 7 levels: 0 is the lowest level and 6 is the highest level of intensity. If the car is on the road, then the levels 2~3 are applied, but if the car collides with a wall or other cars, the 6th step of intensity is applied.



(a) (b) (c) (d)

Fig. 3. Technical implementation of tactile feedback. (a) Game-phone mockup model of a tangible object. (b) Registration of virtual objects to tangible objects with corresponding scale. (c) Internal parts of a tangible object (vibration module, Bluetooth modules, control modules, battery). (d) If a car collides with a wall or other cars, then the intensity of vibration is maximized.

4 Usability Test

4. 1 Task Scenario

We organized the following scenario to evaluate whether providing multi-sensory feedback (e.g. visual/sound/tactile) to users can be helpful for creating more authentic immersion.

Users wearing a 3D HMD on their head interact with a virtual game-phone registered on a tangible object. Users can control a car in a racing game by tilting the tangible object in the directions of up/down/left/right side. As this happens, hand occlusion reduced the visual effect. Sound feedback, such as background-sound/explosion, and vibration feedback when player's car is collide with a wall or other cars are simultaneously provided to the users.

4. 2 Interview and Case Analysis to Derive Items for Usability Test

Through user interviews as well as a case analysis, we derive the items of a usability test concerning the implementation of an AR based product design system providing multi-sensory feedback. Table 2 shows the results.

Table 2. Comments about AR based product design system providing multi-sensory feedback

Advantages	- I was feeling more realistic interaction. - I could have a new experience (environment or senses) - It was very exciting.
Disadvantages	- I was not familiar with these interaction techniques. - It seems uncomfortable in the case of accurate controls. - Reality and tension can be increased, but this has not impacted on the play of the game. - It can deduce the effect of handling.
Etc	- I want to meet suitable senses to the game. - More concrete sensations can be better. - Satisfaction measurement depends on the kind of game.

We can derive usability test items such as Table 3, using comments from users. Derived items are: suitability between contents/context and appropriate sensations, suitability of mapping between control methods and senses, consistency of changing senses and feedback. These items are arranged based on detailed measures for each visual, sound and tactile feedback, as shown in Table 3.

Table 3. Usability test items

Kinds of feedback	Usability test lists
Visual feedback	- Degree of immersion w.r.t. reduction of hands occlusion effect. - Suitability of visual mapping w.r.t tilting method.
Sound feedback	- Suitability of mapping btw given context and sound feedback - Suitability of context aware w.r.t sound feedback. - Suitability btw timing of sound feedback and occurred events
Tactile feedback	- Suitability of mapping btw property of objects and tactile feedback. - Suitability of mapping btw context and tactile feedback - Suitability of vibration effect w.r.t context - Consistency for changes of tactile feedback

5 Experimental Results and Analysis

At first, we evaluate the design environments of a conventional desktop based design environment and of an AR design environment providing multi-sensory feedback. We then quantitatively test the degree of immersion with respect to each visual/sound/tactile feedback, and also test the degree of helpfulness of each feedback in racing games. We qualitatively analyze questionnaires and describe feedback from subjects in each form of feedback.

5.1 Experiment Environment

A survey of the usability test was done using visitors who participated in the next generation computer industry exhibition, KINTEX (Korea International Exhibition Center), Korea, on Nov, 2006. The number of subjects was 45, and the sex ratio of male-to-female was 40:60 respectively. The age ratio of 10/20/30/40 age groups was 12:76:4:8 respectively and most subjects were in their twenties. 38% of subjects had heard about AR/MR research area or experienced relevant systems. Excepting one item about priority, each survey item was evaluated at 5 levels, 1 being the lowest value and 5 the highest value. (1: not very immersive/easy, 2: not immersive/easy, 3: normal, 4: immersive/easy, 5: very immersive/easy).

5.2 AR Based Product Design Environment

Comparing the use of the keyboard or mouse in a desktop environment to observe virtual models, with the use of tangible objects with hands to see models in an AR environment, we asked the following question: “Which environment is more immersive?” 94% of subjects answered that the AR environment was more immersive for observing virtual objects. There were various comments on the question as follows. “Using hands is natural and realistic rather than using a keyboard or mouse,” “This makes interesting interaction,” “I feel a different sensation compared to conventional sensations,” “This system seems to give the feeling of the real experience of a game-phone.”

The next question was: “Which environment is easier to use?” 81% of subjects answered that the AR based product design environment was easier to use compared to a desktop based design environment. Positive comments were “It is comfortable to control using one hand. Also it is a more familiar behavior.” “It is easy to learn, because this method is familiar to me” But there were negative comments such as “Up to now, a computer desktop is easier to use because I have used it for a long time”

Through various comments, we can conclude that accurate input/output are possible in a desktop environment, and there innumerable the users. But we also understand that it takes time to become accustomed to the new operations. On the other hand, an AR environment enables relatively more realistic, intuitive interaction, even though accurate interaction is sometimes difficult.

5.3 Usability Test for Visual Feedback

The first questionnaire was about the degree of immersion w.r.t reduction of hands occlusion effect. As shown in Fig.3 (a), experienced subjects who had heard about new research into AR or had used it, scored on average 4.29 point. Inexperienced subjects scored on average 3.83. On the whole, subject response indicates that the proposed visual feedback can contribute to enhancing immersion. Comments were “when I couldn’t see my hands, I feel heavy.”, “It is more immersive to touch virtual objects using hands, seeing the hands” etc.

The second questionnaire was that “Is this hands occlusion reduced effect helpful to handling a car in a racing game?” On average subjects gave a positive response of 3.76 point. Comments were “It is more realistic, but it is not related to play game” and “The feeling of handling is insufficient” etc.

As a result, both experienced subjects and inexperienced subjects showed positive interactions about shown hands for more immersion. But, because image processing work requires longer computing time, the movement of cars is a little bit slow, and

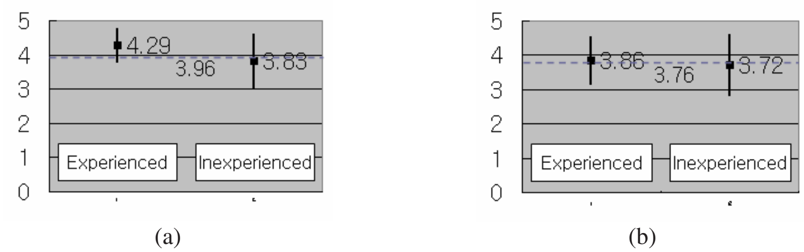


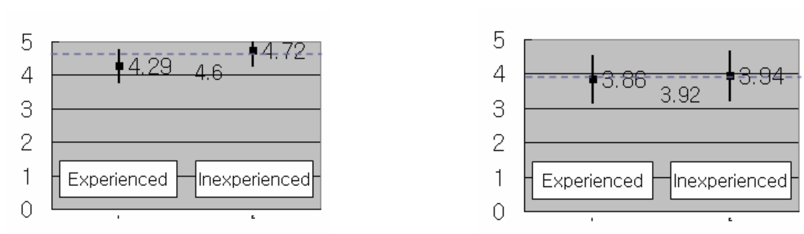
Fig. 4. Usability test for visual feedback (a) Degree of immersion w.r.t. reduction of hands occlusion effect. (b) Degree of helpfulness in playing racing games.

this can reduce the positive effect. Also to explain the difference responses of the experienced and inexperienced subjects, it appears that most experienced subjects were already interested in visual effects and fully understood the problem of the hands occlusion effect.

5.4 Usability Test for Sound Feedback

To the question "Do you think this sound feedback can enhance immersion?" subjects were positive, with an average 4.6 point. One comment was "The degree of immersion is getting higher than before." The next question was "Is this sound feedback helpful to handling a car in racing games?" Most subjects agreed this was the case, with an average 3.92 point. Other comments were "It seems an immersive and present realistic environment.", "more realistic effects are necessary."

We can conclude that sound feedback can contribute to enhancing immersion, but appropriate background-sound and effect sounds for the scenario context are needed. Also more realistic sound effects are necessary. On the other hand, sound feedback has not greatly influenced the degree of helpfulness in playing racing games.



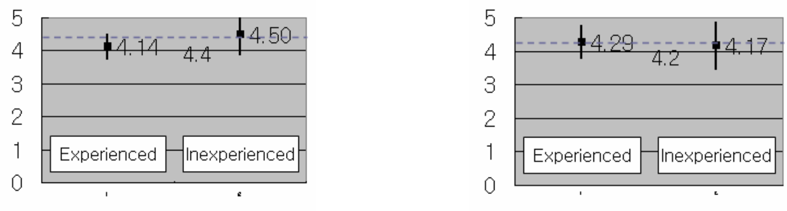
(a) (b)

Fig. 5. Usability test for sound feedback. (a) Degree of immersion w.r.t. sound feedback. (b) Degree of helpfulness in playing racing games.

5.5 Usability Test for Vibro-Tactile Feedback

To the question "Do you think this vibro-tactile feedback can enhance immersion?" subjects answered positively, with an average 4.4 point. One comment in response to this question was "The degree of immersion is getting higher then before." Concerning the intensity of vibration, there was the comment: "Vibration is too strong when the cars collided." Other comments were "Tactile, vibration feedbacks can present good sensations but these should be proper in the game context for more realistic," "I need other types of vibration feedback." The next question was "Is this vibro-tactile feedback helpful to handling a car in racing game?" To this question most subjects also agreed that vibro-tactile feedback was helpful in playing games.

To conclude, vibro-tactile feedback can contribute to enhancing immersion. But vibration feedback should have suitable intensity and be appropriate to the scenario context. Also a range of vibration types is needed.



(a) (b)

Fig. 6. Usability test for vibro-tactile feedback. (a) Degree of immersion w.r.t. vibro-tactile feedback. (b) Degree of helpfulness in playing racing games.

5.6 Priority of Combination of Sensors for Enhancing Immersion

The last questionnaire was "Which combination of sensory feedback can be helpful to enhance immersion? Please prioritize." Combination lists were: "visual+sound feedback", "visual+tactile feedback" and "visual+sound+tactile feedback." Most subjects prefered the combined three sensors: "visual+sound+tactile feedback". The next preference was for "visual+tactile feedback" and "visual+sound feedback." Through these result, we are able to state that tactile feedback is more effective in enhancing immersion than sound feedback.

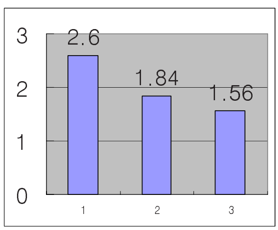


Fig. 7. Priority of feedback. Ordering by visual+sound feedback / visual+tactile feedback / visual+sound+tactile feedback (low number means high Priority).

6 Conclusion

In this paper, we evaluative quantitative/qualitative analysis of usability tests and describe user feedback on proposed methodologies for enhancing immersion, as suggested by paper [1]. The proposed methodologies support multi-sensory feedback to users. In the first usability test, we compare design environments between the conventional desktop environment and an AR environment which enables multimodal feedback. We then addressed each visual/sound/tactile feedback in terms of their ability to enhance immersion and facilitate tasks.

Through qualitative/quantitative usability tests and comments, most subjects agreed that an AR based design environment has some problems in accurate interaction, but it enables a relatively more realistic, intuitive interaction compared to the desktop based design environment. Also most subjects responded positively that multi-sensory feedback can be helpful for enhancing immersion. As a result of the tests for visual feedback, we need to improve the processing time speed for better real-time processing. In sound/tactile feedback, we should consider feedback appropriate to the scenario context, and provide a variety of feedback. Finally, tactile feedback is more effective for enhancing immersion than sound feedback.

Our analyzed results from usability tests on the multi-sensory feedbacks may be useful for enhancing immersion in conventional AR based product design as well as AR based learning and teaching contents for edutainment.

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