An Examination on Effective Auditory Stimulation When Grasping a Virtual Object with a Bare Hand

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***Abstract*— We have been developed an augmented reality (AR) system that gives pseudo-haptic feedback when a user grasps a virtual object with a bare hand. In previous studies, pseudo-haptic feedback was emphasized by adding an auditory stimulus to visual information. However, the effective way of presenting the auditory stimulus has not been studied. Therefore, we investigate the type and presenting method of effective auditory stimulus that gives pseudo-haptic feedback.**

Keywords—augmented reality; interaction; pseudo-haptic; perception;

I. Introduction

In recent years, augmented reality (AR) technology has attracted attention from the world, and interaction between users and virtual objects becomes more important. In conventional studies[1,2], interaction with a virtual object is performed by attaching a device such as markers or gloves to the user. Also, haptic feedback has been given by touching real objects. However, in these methods, the user needs to wear or prepare a device for haptic feedback and therefore discomfort is caused by the attached device.

We have developed an AR system that gives pseudo-haptic feedback when a user grasps a virtual object with a bare hand, without touching the real object[3]. For this system, we referred to the study of multisensory integration[4]. In previous studies, pseudo-haptic feedback was emphasized to the user by giving an auditory stimulus when the user touched or released the virtual object. Although we provided pseudo-haptic feedback in this system, we have not been examined what type and presenting method of auditory stimulus is effective.

Conventional studies on the influence of sound on impression have been actively conducted. One of them[5] reported that, the type of auditory stimulus influenced the haptic impression of the real object. From this result, we expect some type of auditory stimulus to change pseudo-haptic feedback from a virtual object.

In this study, we aim to examine effects of the type of auditory stimulus on pseudo-haptic feedback when a user grasps a virtual object with a bare hand. We focus on sounds with change of volume as our auditory stimulus. We simultaneously present visual information and auditory stimulus in order to obtain the user's pseudo-haptic feedback. The user compares the sense of grasping the virtual object with the sound volume changes and without the sound volume changes. Then, we statistically analyze the comparison data.

Fig. 1. Overview of our AR system

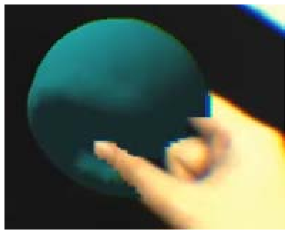

Fig. 2. View from the user through the HMD

The following section explains our AR system.

II. Our Augmented Reality System

In our system, we present visual and auditory information to give pseudo-haptic feedback to a user. Our AR system is composed of a head-mounted display (HMD), a stereo RGB camera, headphones and a head position tracking camera. The overview of our AR system is shown in the Fig.1. The user wears the headphones and the HMD with the stereo RGB camera. The user is given visual information from the HMD and auditory information from the headphones. The process flow of the AR system is as follows:

1. Measure the world coordinates of the fingertips from the image captured with the stereo RGB camera.
2. Determine whether the user is grasping a virtual object by checking the user's fingertip positions and the coordinates of the virtual object.
3. While the user is grasping the virtual object, the following process is performed.
    - 3.1. Deform the virtual object according to the distance between the fingertips.
    - 3.2. Present an auditory stimulus according to the distance between the fingertips.

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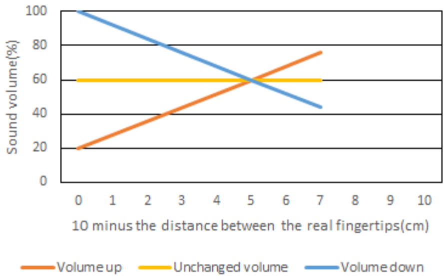
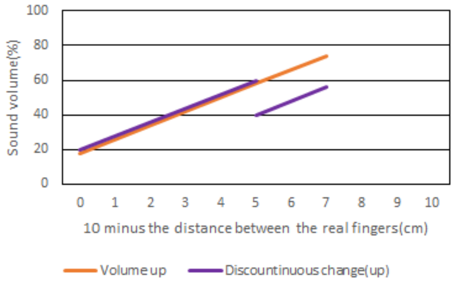
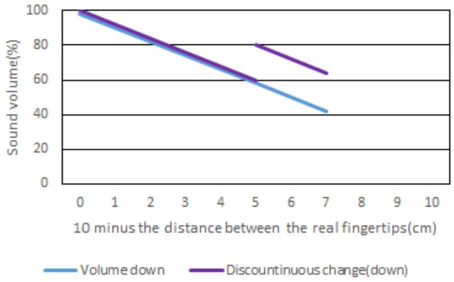


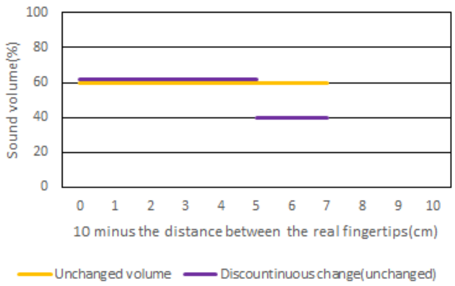
(a) Volume change according to the distance between the user's fingertips



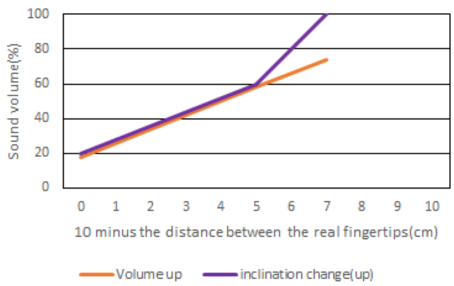
(b) Discontinuous volume change at the core part (increase inclination)



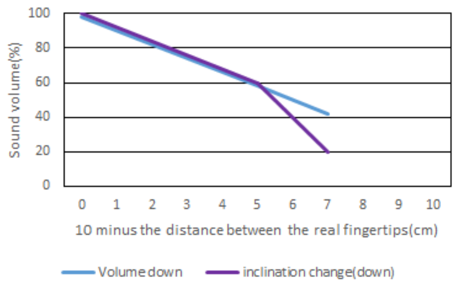
(c) Discontinuous volume change at the core part (decrease inclination)



(d) Discontinuous volume change at the core part (unchanged inclination)



(e) Inclination change at the core part (increase inclination)



(f) Inclination change at the core part (decrease inclination)

Fig. 3. Sound volume changes

A. *Visual information*

We present a virtual soft sphere to the user, and the diameter of the sphere is 10 cm. The user is given visual information through the HMD. The visual information is the virtual object superimposed on the image captured with the stereo RGB camera. A view from the user through the HMD is shown in Fig.2. The user obtains pseudo-haptic feedback by grasping the virtual object with the index finger and the thumb. The determination of grasping the virtual object is performed by the following two conditions:

- The distance between the real fingertips of the index finger and the thumb is in the range of 3 cm to 10 cm.
- The midpoint of the fingertips exists inside the virtual object.

In addition, the virtual object is designed to deform only up to the 5 cm in diameter. If the real fingers enter the inside of the virtual object, the image on the HMD is corrected so that the distance between the fingertips on the HMD is kept 5 cm, and thus the fingertips on the HMD are always touching the virtual object. Also, the hidden-surface removal is performed for the image on the HMD so that the user's thumb can be seen in front of the virtual object.

B. *Auditory Stimulus*

To present an auditory stimulus is effective in providing pseudo-haptic feedback. We assume that the user can perceives the softness of the virtual object when the sound volume changes.

The auditory stimulus is given to the user only while the user is grasping the virtual object. We present a pure tone that is about 523 Hz to the user, and the sound volume changes according to the distance between the user's fingertips. In our system, the sound volume is adjusted in the range of 20% to 100%. Also, the 100% sound volume is set as the volume the user feels just right. The presentation of the auditory stimulus is as follows:

(A) The volume changes according to the distance between the user's fingertips.

(B) The volume changes at the core part of the virtual object.

The reason why we follow (A) is the pseudo-haptic feedback can be obtained by the sound volume change. The reason why we follow (B) is the user can notice the position where the virtual object can't be deformed any further. In other words, (B) is used to solve the problem that the user doesn't know the limit of the position because the virtual object has no entity.

In this study, we conducted a preliminary experiment to select the type of auditory stimuli that gives the user the softness of the virtual object. Preliminary experiment compared the sounds with volume changes at the core part. From results of the preliminary experiment, we selected the auditory stimuli. Fig.3 shows the sound volume changes of the selected auditory stimuli. Fig.3(a) shows three types of auditory stimulus which have different inclinations when the volume changes according to the distance between the user's fingertips" (corresponding to (A)). The three types are:

"Volume up": The sound volume increases as the distance between the user's fingertips decreases.

"Unchanged volume": The sound volume doesn't change regardless of the distance between the user's fingertips.

“Volume down”: The sound volume decreases as the distance between the user’s fingertips decreases.

In the main experiment, the user compares all combinations of two of these three types.

Figs.3(b)-(f) shows five types of auditory stimuli which have the volume change at the core part of the virtual object (corresponding to (B)). Fig.3(b), Fig.3(c) and Fig.3(d) show the discontinuous volume changes, and Fig.3(e) and Fig.3(f) show the continuous volume changes with two inclinations.

“Discontinuous change”: The sound volume discontinuously changes when the user’s fingertip touches the core part of the virtual object (the distance between the user’s fingertips is 5 cm). The inclination of the sound volume doesn’t change.

“Inclination change”: The inclination of the sound volume changes when the user’s fingertip touches the core part of the virtual object (the distance between the user’s fingertips is 5 cm). The sound volume continuously changes.

In the main experiment, the user compares two auditory stimuli with and without the volume change shown as the purple lines in Figs.3(b)-(f).

III. Impression Evaluation Experiment

We experimented whether the user perceives differences in the user’s pseudo-haptic feedback by our AR system. In the following subsection, we detail various items (participants, apparatus, procedure, and design)

A. Participants

Ten volunteer participants (6 male, 4 female) were recruited from the local university campus. The Participants ranged from 18 to 26 years old. Some of the participants had little knowledge about AR, but no one was familiar with AR.

B. Apparatus

The hardware consisted of a PC (4.0GHz Intel core i7-4790K with a RAM of 16GB), an HMD (Oculus Rift DK2, Oculus VR), a stereo RGB camera (Ovrvision Pro, Wizapply), headphones (ATH-M20x, audio-technica) and a head position tracking camera (an accessory of the HMD). The participants wore the HMD and the headphones to obtain visual information and auditory information. The stereo RGB camera was attached to the HMD. The processing speed of our AR system was about 25 FPS.

C. Procedure

An overhead view of the experimental environment is shown in Fig. 4. The participant seated in front of the head position tracking camera and wore the HMD and the headphones.

First, hue information of participant hands and parallax of participant were set for each participant. After that, the participant executed practice trials to get used to our AR system. The practice trial presented only visual information without auditory stimulus to avoid the influence of the auditory stimulus in the practice trial. The task which the participant preformed with a virtual object was as follows:

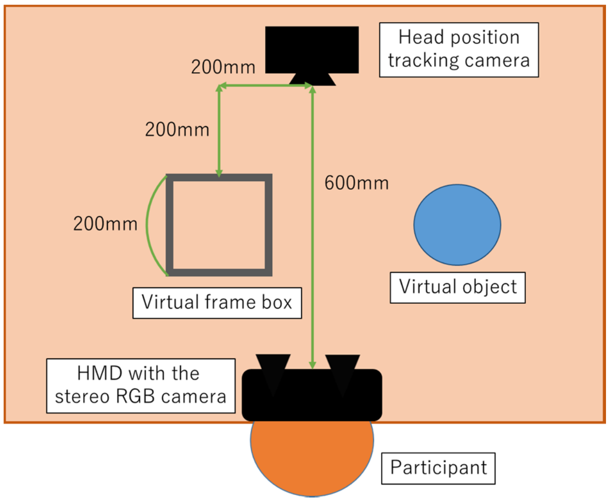


Fig. 4. Overhead view of the experimental environment

1. The participant grasps the virtual sphere displayed on the HMD with the thumb and the index finger.
2. The participant deforms or moves the virtual sphere to check softness and operability.
3. The participant moves the virtual sphere into the virtual frame box displayed on the HMD and releases it.

This task was performed for two compared stimuli, and the participant orally answered questions about evaluations of the two compared stimuli.

After a few practice trials, the participants performed the main evaluations just like they did the practice trials. In the evaluation, the participant compared the two auditory stimuli that is:

(A’) Two auditory stimuli chosen from the three sound volume changes in Fig.3(a).

(B’) Two auditory stimuli with and without the volume changes in one of Fig.3(b)-(f).

D. Design

The participant compared each pair of the auditory stimuli and answered the following questions:

(i) Which virtual object is softer?

(ii) Which virtual object do you feel to be more completely in your hand?

(iii) Which is a virtual object that can be moved more easily?

(iv) Which virtual object is heavier?

(v) Which is a virtual object that can be grasped more easily?

In each comparison, we defined the first virtual object as A and the second virtual object as B. The participant orally answered the questions by choosing “A” or “B”.

Each participant conducted 16 comparisons ((3 comparisons about (A’) stimuli + 5 comparisons about (B’) stimuli) x 2 (including the reverse order)). As a result, the number of evaluations was 160 (= 10 participants x 16 comparisons).

Table 1. Compared auditory stimuli in the experiment

	A	B
(1)	Volume up in Fig.3(a)	Volume down in Fig.3(a)
(2)	Volume up in Fig.3(a)	Unchanged volume in Fig.3(a)
(3)	Unchanged volume in Fig.3(a)	Volume down in Fig.3(a)
(4)	Discontinuous change in Fig.3(b)	Volume up in Fig.3(b)
(5)	Discontinuous change in Fig.3(c)	Volume down in Fig.3(c)
(6)	Discontinuous change in Fig.3(d)	Unchanged volume in Fig.3(d)
(7)	Inclination change in Fig.3(e)	Volume up in Fig.3(e)
(8)	Inclination change in Fig.3(f)	Volume down in Fig.3(f)

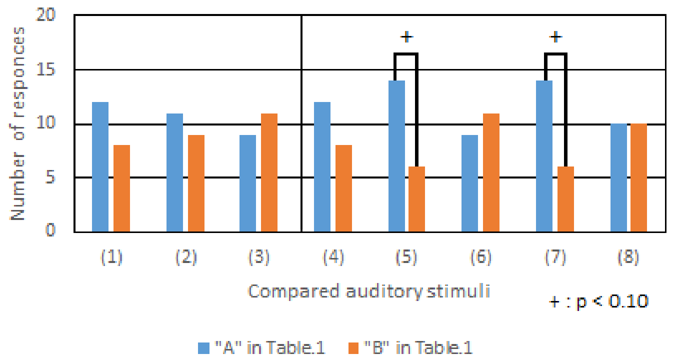


Fig. 5. Results of the evaluation on the softness

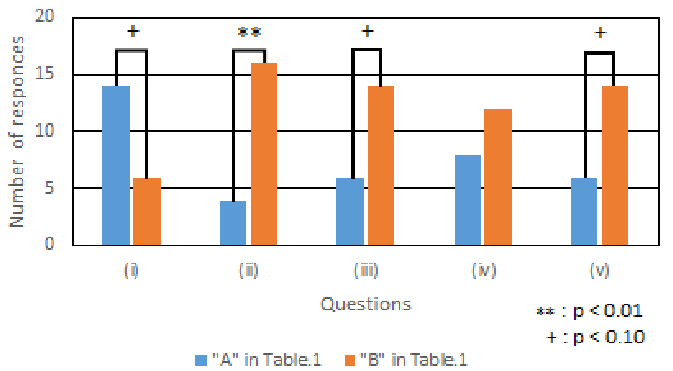


Fig. 6. Results of the comparison about (7) in Table1

IV. Result and Discussion

We collected 160 evaluation data and analyzed statistically for every question. The stimuli A and B compared in the experiment are shown in Table1. We conducted binomial analysis for the difference between the total of answers “A” and the total of answers “B” in Table1. Among these analysis results, this paper describes noticeable results that are a result of the evaluation on the softness (question (i)) and a result of the comparison (7) in Table1.

The result of the evaluation on the softness (question (i)) is shown in Fig.5. In Fig.5, there are marginally significant differences for the comparisons (5) and (7) (both, $p = 0.058$, $0.05 < p < 0.10$). Both comparisons (5) and (7) used the auditory stimuli with the volume increase at the core part. Therefore, the volume increase at the core part made the participants feel the virtual object softer than no volume increase at the core part.

The result of the comparison (7) in Table1 is shown in Fig.6. In Fig.6, there are a significant difference for the question (ii) ($p = 0.006 < 0.01$) and marginally differences for the questions (i), (iii) and (v) (all three, $p = 0.058$, $0.05 < p < 0.10$). From the question (i), the participants felt that the virtual object that was presented with the inclination change of the volume increase at the core part was softer than that without the inclination change at the core part. From the questions (ii), (iii) and (v), the participants felt that it was difficult to grasp the virtual object with the inclination change at the core part. The comparison (7) focused on the continuous volume increase that emphasized the increase at the core part. Therefore, the continuous volume increase emphasized at the core part gave the participant the impression that the virtual object would be softer and more deformable than they thought before the core part, and this impression made the participant difficult to hold the virtual object.

V. Conclusion

In this study, we aimed to examine effects of auditory stimulus with a change of sound volume on pseudo-haptic feedback from a virtual object.

As the results of our study, we found that the participants received different impressions by the auditory stimuli with the volume change. We found that the participants felt the virtual object soft with the volume increase given at the core part of the virtual object. In addition, we found that the participants felt the virtual object soft and deformable by emphasizing the volume increase at the core part of the virtual object. These findings are useful for improving perception of grasping a virtual object with a bare hand and for giving pseudo-haptic feedback to a user.

In the future, we increase the number of trials for reproducibility and also we investigate whether the volume change is useful for non-pure tones.

Acknowledgment

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References

[1] Volkert Buchman, et.al, “FingARtips-Gesture Based Direct Manipulation in Augmented Reality,” Proc.International Conf.on Computer Graphics and Interractive Techniques, pp.212-221, 2004.

[2] Holger Regenbrecht, et.al, “Virtual Reality Aided Assembly with Directional Vibro-Tactile Feedback,” Proceedinf of the 3rd international conference on Computer graphics and interactive tecniques in Australasia and South East Asia, pp.381-387, 2005

[3] Sho Kato, et.al, “An Examination of Perception with an Auditory Cue When Grasping a Virtual Object with a Bare Hand” The 2017 International Workshop on Advanced Image Technology, SESSION 3A, 2017.

[4] Shunichi Kawabata, et.al, “Study of an interaction between haptic, auditory and visual,” IEICE Technical Report, MBE2010-101, pp.121-124, 2011.

[5] Steve Guest, et.al, “Audiotactile interactions in roughness perception,” Experimental Brain Research, Vol 146, pp 161-171, 2002