Joint Virtual Reality Conference of ICAT - EGVE - EuroVR (2012)
R. Boulic, C. Cruz Neira, K. Kiyokawa, and D. Roberts (Editors)

Modifying an Identified Size of Objects Handled with Two Fingers Using Pseudo-Haptic Effects

Y. Ban[1], T. Narumi[1], T. Tanikawa[1], and M. Hirose[1]

[1]Information Science and Technology, The University of Tokyo, Japan

Abstract

In our research, we aim to construct a visuo-haptic system that employs pseudo-haptic effects to provide users with the sensation of touching virtual objects of varying shapes. Thus far, we have proved that it can be possible to modify an identified curved surface shapes or angle of edges by displacing the visual representation of the user's hand. However, this method has some limitations in that we can not adapt the way of touching with two or more fingers by visually displacing the user's hand. To solve this problem, we need to not only displace the visual representation of the user's hand but also deform it. Hence, in this paper, we focus on modifying the identification of the size of objects handled with two fingers. This was achieved by deforming the visual representation of the user's hand in order to construct a novel visuo-haptic system. We devised a video see-through system, which enables us to change the perception of the shape of an object that a user is visually touching. The visual representation of the user's hand is deformed as if the user were handling a visual object, when in actuality the user is handling an object of another size. Using this system we performed an experiment to investigate the effects of visuo-haptic interaction and evaluated its effectiveness. The result showed that the perceived size of objects handled with a thumb and other finger(s) could be modified if the difference between the size of physical and visual stimuli was in the range from -40% to 35%. This indicates that our method can be applied to visuo-haptic shape display system that we proposed.

Categories and Subject Descriptors (according to ACM CCS): H.5.1 [Information Interfaces and Presentation (I.7)]: Multimedia Information Systems—Artificial,augmented,and virtual realities

1. Introduction

Haptics have become an important modality in recent virtual reality (VR) systems, and several haptic devices have recently been developed [MS94,HT99,Iwa01]. However, because it is difficult to perfectly reproduce the force that we perceive when touching an object, most haptic devices exhibit very complicated problems. As a result, it is difficult to apply haptic devices to widely used systems, because a large amount of preparation work, such as installation and calibration, must be performed for each user.

While research on haptic presentation in VR systems often concerns active haptics, an increasing number of works focus on alternative approaches such as passive haptics, which include pseudo-haptics and sensory substitution. Pseudo-haptics represent a kind of cross-modal phenomenon between our visual and haptic senses [LCK*00]. The pseudo-haptic approach is a potential solution for exploiting the boundaries and capabilities of the human sensory system to simulate haptic information without using active haptic systems. For example, when we are working on a computer, the slowdown of the cursor evokes a virtual frictional force on our hand holding the mouse. This phenomenon can potentially generate haptic sensations using only visual feedback, without the need to apply any physical devices.

In our research, we use this cross-modal effect to "change" the shape of an object, and construct a simple system that can display a variety of shapes, while the user touches only a simple static physical object (Figure 1). In other words, by using a visual display and physical device, we aim to exploit visual feedback to widen the range of what can be physically represented by the device. This system evokes a pseudo-haptic effect by controlling the displacement of a user's hand in the image showing the user touching

DOI: 10.2312/EGVE/JVRC12/001-008

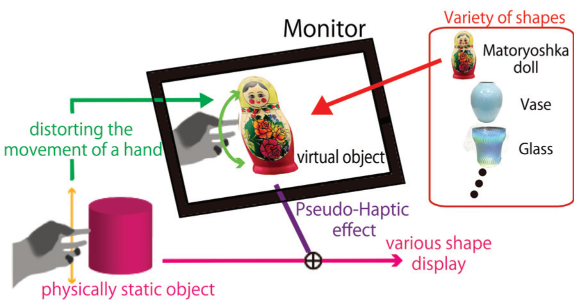


Figure 1: *Displaying the shape of an object using the pseudo-haptic effect*

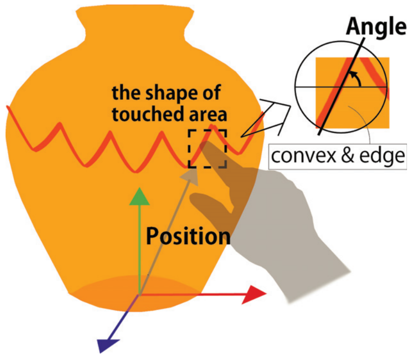


Figure 2: *Requirements for shape display*

the static object. By exploiting this effect in simple devices, we can change the user's perception of the shape.

Using our system, we aim to display complicated shapes that are composed of primitives. Our system concept is presented in Figure 2. To realize this concept, we must develop two capabilities. First, we need to display primitives (i.e. convex, edge, concave, etc.) near the point of contact. Second, we need to set the relative postures of these primitives with an object. By combining these two capabilities, we can exploit the pseudo-haptic effect and display various shapes without applying any physical devices.

First, we used our simple system to confirm the possibility of displaying primitives of areas touched by the user. In particular, we proved that using the pseudo-haptic effect, users can perceive a variety of curved shapes, while touching only a physically static cylinder [BKN*12b].

Second, we examined the possibility of exploiting the pseudo-haptic effect to modify an identified placement, especially the angles of primitives. The result of this experiment proved that the perceived angles of edges can be modified if the difference of angles between edges is in the range of $-35°$ to $30°$ [BKN*12a].

These experiments suggested the possibility of our shape display system. However, this system has some limitations. One of the main limitations is that this system adapts the manner of touching only for a single finger, not for two or more fingers as used in pinching, grasping, and so on. With visual displacement of a user's hand alone, we cannot adapt to the situation in which there are two or more contact points between an object and a hand. To realize the proposed system, we must realize a means not only for displaying various complicated shapes but also for adapting to various ways of touching such as those shown in Figure 3.

In this paper, to solve this problem, we propose a method of modifying an identified size of objects not only by displacing the visual representation of the user's hand but also by deforming it as if the user were handling the virtual shape. This method gives the users the impression that they are handling the virtual shape, although in actuality they are handling another shape.

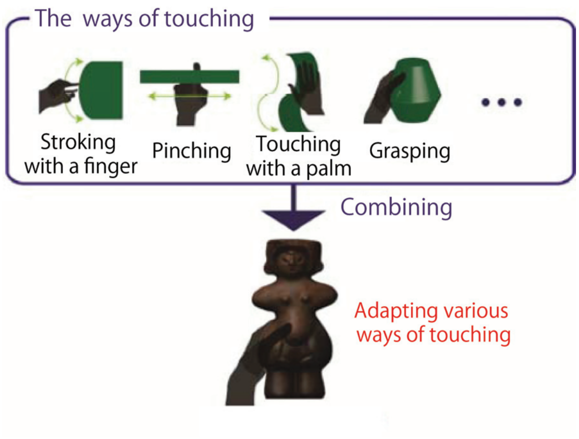


Figure 3: *Various ways of touching*

We construct an algorithm to generate the visual feedback necessary to provoke the pseudo-haptic effect. We then use this algorithm to examine the possibility of exploiting the pseudo-haptic effect to modify an identified-size object handled with two fingers, and thereby confirm the availability of this algorithm for our proposed shape display system.

2. Related Work

While much research has been conducted on cross-modal effects between our haptic sense and other senses, herein, we mainly focus on the effects between our haptic sense and vision, which we aim to use in our system.

Haptic illusion that combines a presentation of forces with a manipulation of visual stimuli has a long history, dating back to Charpentier's size-weight illusion [MEBR99], which showed that subjects estimated the weights of objects of equal mass on the basis of their apparent sizes. His work revealed that subjects felt an object was lighter when it appeared larger in their vision.

Pseudo-haptics, which is one of the illusional phenomena triggered by this characteristic of our sense, was first presented by Lécuyer [Léc09]. Lecuyer et al. made subjects push their thumb against a piston which was in turn pushed against an isometric Spaceball device. Simultaneously, subjects were visually presented with the compression of a virtual spring. Even though the Spaceball was not compressed, the perception of stiffness was influenced by the virtual spring. We can easily attempt to reproduce this effect in PowerCursor [PC], a Flash toolkit used to create interfaces that a user can touch. This toolkit was developed by Mensvoort during his work on simulated haptic feedback [vM02]. Pusch et al. proposed a pseudo-haptic approach, called HEMP, hand-displacement-based pseudo-haptics, which provides haptic-like sensations by displacing a visual representation of the user's hand [PMC09]. They showed that when a subject wearing a head-mounted video see-through display (HMD), placed a hand in the opening of a pipe, and the HMD presented a virtual image of the hand moving to the right, the subject felt a force on the hand even though no physical force was exerted.

In addition, some research results show the potential for pseudo-haptic effects on our perception of not only force but also texture [ISK*08, LBT08] and shape. Research has shown that when we are presented with conflicting sensory stimuli, vision usually dominates our perception of shape. Gibson's work [Gib33] is an example of this type of research, which showed that a subject moving his or hera hand along a straight flat surface while wearing distorting glasses, feels the straight surface as if it were curved. We can also consider the work of Rock and Victor as another example [RV64]. They asked their subjects to hold an object with a cloth while viewing the same object through a distorting lens. In this experiment, subjects matched the shape of the test object to the shape most similar to the distorted visual image they saw, rather than to the shape they actually touched. Kohli et al. found that distorting the pointer showing the position of the device along a flat surface of the desk can change the perception of the shape of the surface [Koh09]. Their work revealed that when subjects traced the device on a flat surface with the visual presentation as if they were tracing it on a curved surface, they perceived the curved one in their vision.

Other research work has revealed that in some cases, even though visual stimuli are not given complete priority over haptic stimuli, cross-modal effects between these two sensations influence our perception to some extent. Nakahara et al. found that when users of a mixed-reality system are presented with haptic and visual cube-shaped objects having discrepant edge curvatures, they perceive the curvature as somewhere between those of the two objects [NKO07].

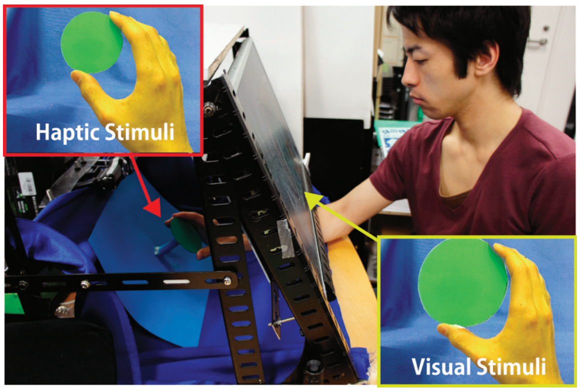


Figure 4: *Shape display system using the effect of a visuo-haptic interaction*

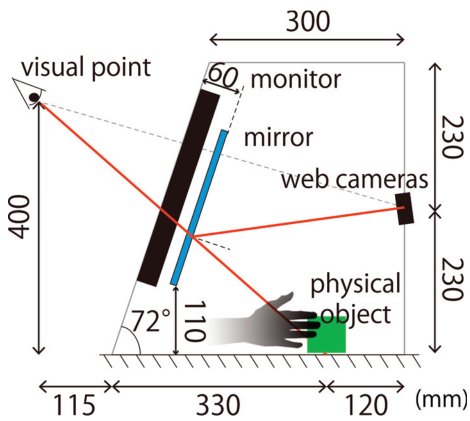


Figure 5: *Dimensions of our shape display system*

3. Modification of an Identified Size of Object Held with Two Fingers

To realize the modification of an Identified size of object held with two fingers, we constructed a visuo-haptic system using the pseudo-haptic effect by deforming a visual representation of the user's hand.

3.1. Visuo Haptic Video See-Through System

We constructed the simple video see-through system as shown in Figure 4. In this system, users are deceived that they are touching virtual objects whose shapes are different from the physical objects that they are actually touching. Users touch a physical object placed behind a visual monitor and view it through the 3D monitor.

We placed two web cameras at locations corresponding to a user's eyes through a mirror, and we captured images around the user's hand. In this geometry, the binocular parallax is achieved by setting the distance between the cameras to 65 mm. The users sat on a chair and we nudged their heads to the viewing position that we had established. Using

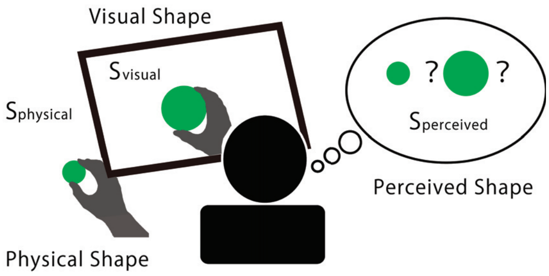


Figure 6: *Experiment for modifying the identified size of an object*

the images captured by the cameras, the system realizes a stereoscopic video see-through display (Figure 5).

Touching the physically static object, whose shape is defined as $S_{physical}$, serves as the haptic stimulus. Watching an image as if the user were touching another object, whose shape is defined as S_{visual}, serves as the visual stimulus. The shape of the object reported by the user as the one perceived as touching is defined as $S_{perceived}$. In this system, we aim to change $S_{perceived}$ by changing S_{visual} to a variety of shapes and by provoking the pseudo-haptic effect, but without changing the $S_{physical}$ of the object.

Using the video see-through system we composed, we conducted an experiment on the effects of pseudo-haptics on our perception of size of objects handled with two fingers (Figure 6). To simplify measuring the differences among $S_{physical}$, S_{visual} and $S_{perceived}$, we chose a disk as the shape of the objects that subjects touched in the experiment .

3.2. Algorithm for Conposition of Visual Feedback

In this study, we constructed an algorithm to generate the visual feedback necessary to provoke the pseudo-haptic effect and enable users to perceive objects of various sizes with only a single object of fixed size.

According to the procedure described in the following sections (see Figure 7), an image (I_{vf}) for visual feedback is composed from the images (I_c) taken by the two cameras attached.

3.2.1. Extraction of Object and User's Hand from Captured Image (I in Figure 7)

First, we extracted the area of the object and the user's hand from the captured image on the basis of color. We created a blue background with a chroma key, which simplified color extraction.

3.2.2. Object Scaling (II in Figure 7)

We scaled the appearance of the object (up or down) while maintaining the centroid of its area. Here we defined the scale factor as R. In addition, we calculated the change of the object's area.

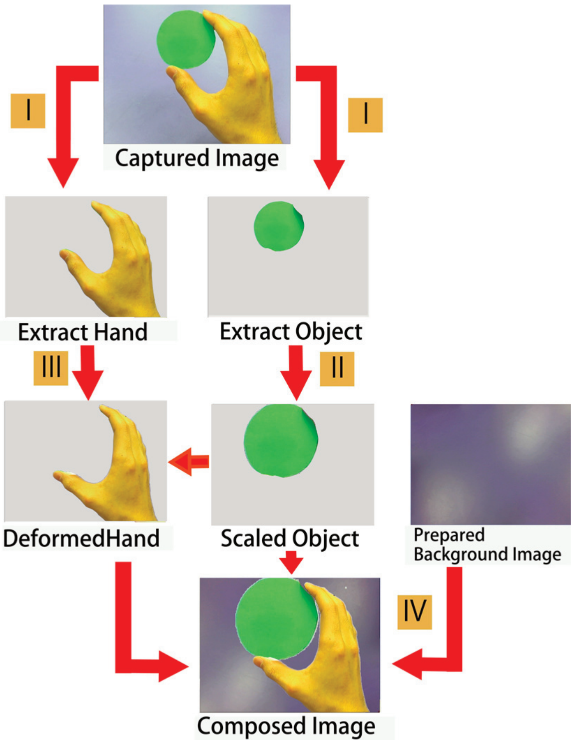


Figure 7: *Image processing method for scaling the appearance of object*

3.2.3. Hand Deformation (III in Figure 7)

We used a deformation algorithm based on the position of control points on the hand [STJ06]. Using this algorithm, we deformed the shape of the hand easily and naturally using three control points. We defined the points where the user's fingers contacted the object as contact points. The two points of contact between the object and hand, along with the centroid of the hand, are referred to as the control points. Below we describe the algorithm generated to deform the shape of the hand naturally for this particular grip.

We mainly focus on the situation where the user holds the object with a thumb and other finger(s); this can be seen in the upper image of Figure 7. The system uses the two contact points between the object and hand (one is on the thumb and the other is on the index finger) and the centroid of the user's hand as the control points. Before we calculated the hand deformation, we detected the user's two fingers with which s/he held the object and the position where his/her fingers contacted the object.

The first contact point was detected as the point of the user's hand nearest to the centroid of the detected object area (O_{object}). This contact point is denoted by F_1.

The second contact point was detected as the point nearest to O_{object} in the portion of the user's hand excluding the

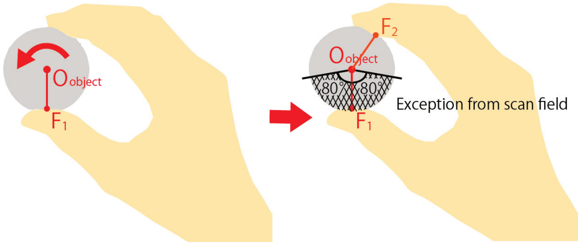


Figure 8: *Detection of contact points between object and fingers. O_{object} is the centroid on the area detected as the object. F_1 and F_2 are contact points between hand and object.*

vicinity of F_1. This contact point is denoted by F_2. We defined an excepted sector in terms of its center, which is the line F_1O_{object}, and its central angle, which is $\pm$ 80°. This sector is shown as the meshed area on the right in Figure 8. The detected contact points (F_1, F_2), and the centroid of the user's hand (O_{hand}), are used as the control points before deformation.

Figure 9 shows how we deformed the shape of the user's hand. During the deformation process, we replaced F_1 and F_2 with F_1' and F_2' where the user's fingers contacted the virtually scaled object according to the change in the area of the object, as calculated in Section 3.2.2. In other words, we enlarged or shrunk F_1O_{object} and F_2O_{object} by a factor R, as described in the following expression for determining the coordinates of F_1' and F_2'.

$$F_1O_{object} : F_1'O_{object} = F_2O_{object} : F_2'O_{object} = 1 : R$$

We then used these two replacement control points (F_1', F_2') and the centroid of the user's hand (O_{hand}) as the updated control points. Based on the algorithm described by Schaefer et al. [STJ06], we deformed hand to move from F_1 , F_2, and O_{hand} to F_1' , F_2', and O_{hand}. While above-mentioned figures show the situation when a user's thumb is detected first, this algorithm works well even if a user's index finger is detected first.

3.2.4. Image Composition (IV in Figure 7)

Finally, we overlaid the images of the scaled object and deformed hand over the background image that we had prepared in advance. This is used for visual feedback. Furthermore, this method tolerates other grip types. Figure 10 shows the result of image processing for scaling an object held by hand.

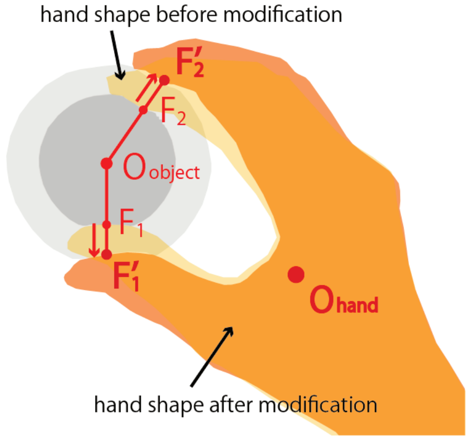


Figure 9: *Scaling of object and deformation of hand*

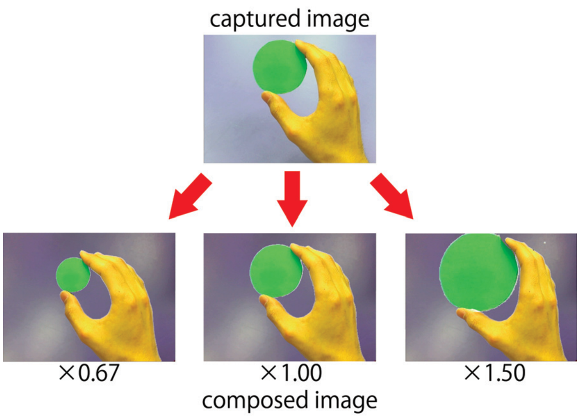


Figure 10: *Result of scaling an object in appearance*

4. Measurement of the Ability of Modifying an Identified Size of Objects

4.1. Purpose of the Experiment

We investigated the ability of our shape-display system based on the pseudo-haptic effect to control the perception of size of an object handled with two fingers. We conducted an experiment to examine how the effect of S_{visual} changed $S_{physical}$ to $S_{perceived}$, and compared these three shapes. If $S_{perceived}$ resembled S_{visual} rather than $S_{physical}$, then we concluded that the visuo-haptic interaction was effectively provoked, meaning that the system worked as designed. Conversely, if $S_{perceived}$ resembled $S_{physical}$ rather than S_{visual}, then we concluded that the haptic stimuli was more influential for the perceived shape rather than the visual one. Thus, when the latter result was obtained, it indicated that it was difficult for our system to modify an identified a size of an object handled with two fingers, a thumb and other finger(s). Hereinafter,we refer to the diameters of these three shapes as $D_{physical}$, D_{visual} and $D_{peceived}$.

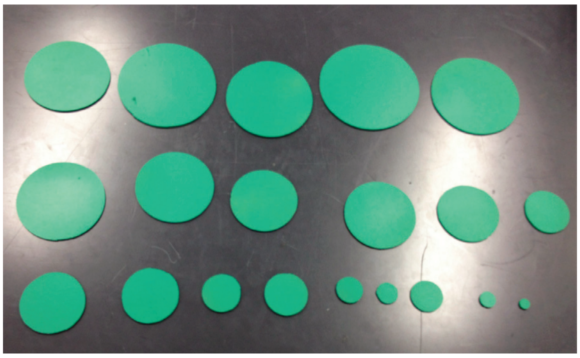


Figure 11: *Subjects matched the size of a handled object by choosing from so-called answer disks*

4.2. Pre-Experiment

Before we performed the experiment, we conducted a pre-experiment to measure the ability to perceive the size when a subject handled an object with two fingers. We showed subjects a captured image on the monitor, and they reported the sizes of objects that they handled behind the monitor. Thus, in this pre-experiment, $S_{physical}$ and S_{visual} were the same size.

The subjects reported the size of a handled object by choosing the disk that they felt was the nearest in size from among the disks of various sizes. The diameters of these disks ranged from 5 mm to 110 mm with a step of 5 mm (Figure 11). Each subject chose one of these disks and then handled it with the same hand as for $S_{physical}$ to compare the sizes of this disk and $S_{physical}$. Repeating this trial, the subjects chose the disk that they felt matched the disk behind the monitor. We call these disks the answer disks.

We chose disks of three sizes as $S_{physical}$. The diameter of these disks was 30 mm, 55 mm, and 80 mm. Five men in their twenties participated in this pre-experiment and four trials were conducted for each $S_{physical}$.

Table 1 shows the result of this pre-experiment. These results show that the size of $S_{perceived}$ was almost the same as the size of $S_{physical}$ and S_{visual}. This proves that the video see-through system functioned successfully for the perception of size. Throughout all trials, the difference in size between $S_{physical}$ and $S_{perceived}$ was within $\pm$ 5 mm, so the perception error for the sizes of the objects was within that range. Using this result, we conducted the experiment to investigated the ability of our shape-display system based on the pseudo-haptic effect to control the perception of size of an object handled with two fingers.

4.3. Experiment

In this experiment we chose disks of three sizes as $S_{physical}$. The diameter of these disks was the same of the pre-experiment, 30 mm, 55 mm, and 80 mm. For each size of $S_{physical}$, the subjects were shown disks whose diameter are from ($D_{physical}$ - 30) mm to ($D_{physical}$ + 30) mm every 10 mm as S_{visual}. This interval of the diameter of S_{visual} was determined by the ability of the perception of size we estimated from the result of the pre-experiment. Nine men and a woman in their twenties participated in this experiment, and two trials were conducted for each combination of $S_{physical}$ and S_{visual}. These combinations were presented to subjects in a random order.

Table 1: *Sizes of objects that subjects felt handling*

$D_{physical}$ (mm)	Means (mm)	SDs	Rate (%) of $D_{physical} \neq D_{perceived}$
30.00	29.75	1.09	5
55.00	54.75	1.92	15
80.00	80.25	1.92	15

We set no time limit for the subjects to answer what size they felt, but we gave them the following five instructions.

- Subjects must watch the image presented on the monitor when touching the object.
- Subjects must touch the object with a thumb and other finger(s).
- Subjects must handle the mid line of the object.
- Subjects must touch $S_{physical}$ and “the answer disks" with their same hand.
- Subjects may touch $S_{physical}$ and “the answer disks" repeatedly.

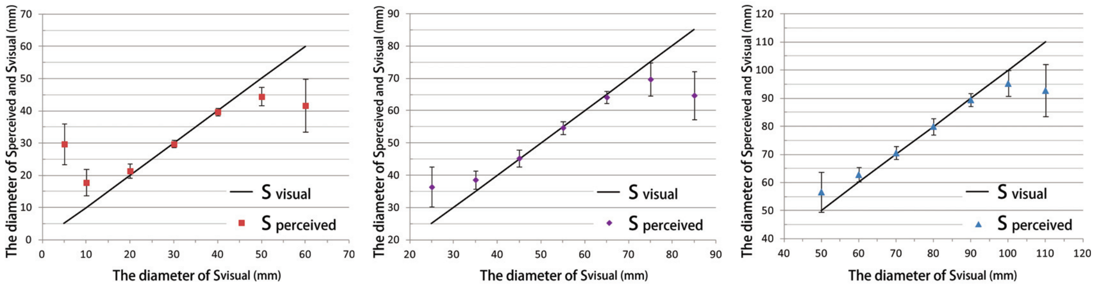
We did not restrain the heads of the subjects with any equipment. Instead, we instructed them not to move their heads from the position that we initially set in realizing the video see-through system. We measured the position of the heads of the subjects, and confirmed that the subjects watched the correct video see-through image on the monitor.

During the experiment, the subjects were not aware that they actually touched only one kind of $S_{physical}$. In each trial the experimenter only went through the motions of changing $S_{physical}$. In addition, the experimenter did not indicate whether the hand position in the monitor was actually distorted or not, and thus the subjects did not know whether S_{visual} was the same as $S_{physical}$.

As in the pre-experiment, the subjects reported the size of a handled object by choosing the disk that they felt was the nearest in size from among the disks of various sizes.

4.4. Results and Discussion

As our experimental result, we present the diameter of $S_{perceived}$. Figure 12 shows the $D_{perceived}$ when 30 mm, 55 mm and 80 mm diameter disks were presented as $S_{physical}$. Two observations are common to these three results. The first is that $D_{perceived}$ is almost same as D_{visual} when D_{visual}



(a) $D_{physical} = 30mm$ (b) $D_{physical} = 55mm$ (c) $D_{physical} = 80mm$

Figure 12: *Perceived size of objects modified by S_{visual} (means and SDs)*

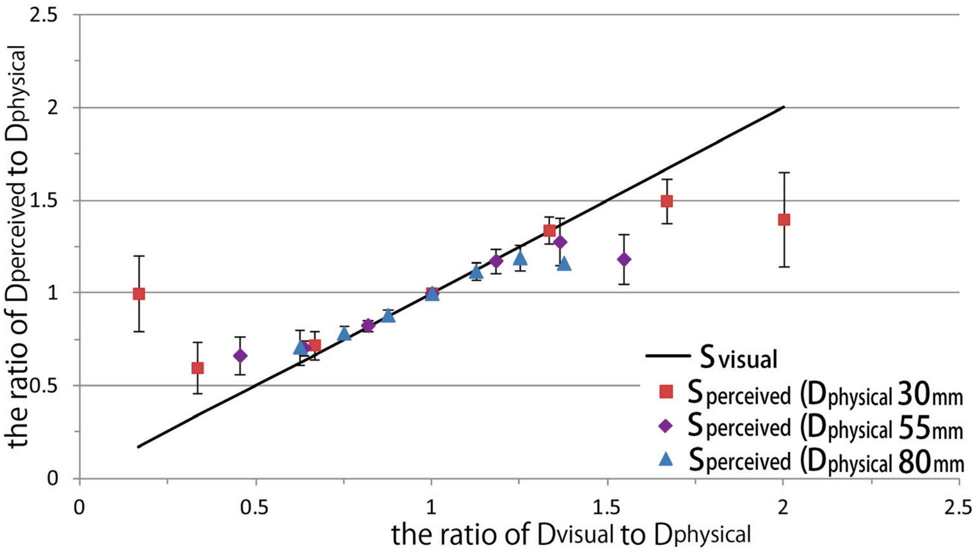


Figure 13: *Size of objects that subjects felt handling (means and SDs)*

is less than ± 10 mm compared with $D_{physical}$. This suggests that our proposed method, deforming the visual representation of user's hand can modify the perception of size of object handled with two fingers if the difference of size between visual and haptic stimuli is within ± 10 mm, regardless of the size of the object that the subjects actually touch. The second observation is that $D_{perceived}$ differs widely from D_{visual} when D_{visual} is outside ± 30 mm compared to $D_{physical}$. This indicates that it is difficult to modify the perception of size if the difference between the diameters visual and haptic stimuli is greater than 30 mm. By comparing the results of Figures 12(a) and 12(c), it can be seen that the difference between D_{visual} and $D_{perceived}$ is greater when $S_{physical}$ is a 30-mm disk than when $S_{physical}$ is an 80-mm disk. The cause of this difference is apparently the difference in the ratio between $D_{physical}$ and $D_{physical}$. The perception of size is influenced by not only the absolute size difference but also the size ratio .

We arrange the results according to the size ratio between $S_{physical}$ and S_{visual}. Figure 13 shows that there is almost no difference between D_{visual} and $D_{perceived}$ if the ratio between $D_{physical}$ and D_{visual} is within the range from 0.6 to 1.35. Conversely, the difference between D_{visual} and $D_{perceived}$ becomes large when the ratio of $D_{physical}$ to D_{visual} is less than -50% or greater than 50%. This result indicates that we can modify an identified size of object if the ratio between visual and haptic stimuli is within the range from -40% to 35%.

5. Conclusion and Future Work

This paper evaluates the effectiveness of using a visuo-haptic shape display system for modifying an identified size of object handled with a thumb and other finger(s). This system uses a pseudo-haptic effect based on the visual deformation of a user's hand touching an object.

To realize the proposed system, we must realize a means for not only displaying various complicated shapes but also adapting to various ways of touching such as pinching and grasping. Thus, we need to not only displace the visual representation of the user's hand but also to deform it. In this study, we focused on modifying an identified size of an object handled with a thumb and a other finger.

We constructed an algorithm to generate the visual feedback necessary to provoke the pseudo-haptic effect by deforming the visual representation of the user's hand as if the user were handling the virtual shape. We conducted an experiment to evaluate the effectiveness of the proposed algorithm, and a large portion of the subjects felt that they were not handling an object the size of the haptic stimulus, but rather an object of the size visually presented. This experiment proved that our algorithm can modify the perceived size of an object if the difference in size between the visual and haptic stimuli is within the range from -40% to 35%.

Thus, we conclude that it is possible to modify an identified size of an object by using visual feedback, and so this algorithm can be applied to the visuo-haptic shape display system we proposed. To derive more detailed specifications for the system, we should examine whether it is possible to modify the identified position and shape using this algorithm. Based on these measurements, we should have the proposed system adapt to various ways of touching. Then, we should decide on the range and accuracy of shapes to generate with physical devices. Finally, we can design the physical devices and visual display to generate the visual feedback and thus construct a system that provides users with the sense of freely touching a variety of shapes.

6. Acknowledgements

This work was partly supported by the Grant-in-Aid for challenging Exploratory Research(11015187).

References

[BKN*12a] BAN Y., KAJINAMI T., NARUMI T., TANIKAWA T., HIROSE M.: Modifying an identified angle of edged shapes using pseudo-haptic effect. *Euro Haptics 2012* (2012). 2

[BKN*12b] BAN Y., KAJINAMI T., NARUMI T., TANIKAWA T., HIROSE M.: Modifying an identified curved surface shape using pseudo-haptic effect. *The 2012 IEEE Haptics Symposium (HAPTICS2012)* (2012), 211 – 216. 2

[Gib33] GIBSON J.: Adaptation, after-effect, and contrast in the perception of curved lines. *Journal of Experimental Psychology 16* (1933), 1–31. 3

[HT99] HOSHINO H., TACHI S.: Realization and utillization of 3d cyber space. a method to represent an arbitrary surface in encounter type shape representation system. *Transactions 4* (1999), 445–454. 1

[ISK*08] IESAKI A., SOMADA A., KIMURA A., SHIBATA F., TAMURA H.: Psychophysical influence on tactual impression by mixedreality visual stimulation. *Transactions of the Virtual Reality Society of Japan 13*, 2 (2008), 129–140. 3

[Iwa01] IWATA H.: Project feelex: adding haptic surface to graphics. *SIGGRAPH 2001 Conference Proceedings* (2001), 469–475. 1

[Koh09] KOHLI L.: Exploiting perceptual illusions to enhance passive haptics. *IEEE VR Workshop on Perceptual Illusions in Virtual Environments* (2009), 22–24. 3

[LBT08] LECUYER A., BURKHARDT J., TAN C.: A study of the modification of the speed and size of the cursor for simulating pseudo-haptic bumps and holes. *ACM Transaction on Applied Perception (ACM TAP) 5* (2008). 3

[LCK*00] LECUYER A., COQUILLART S., KHEDDAR A., RICHARD P., COIFFET P.: Pseudo-haptic feedback: Can isometric input devices simulate force feedback. *Proc. IEEE VR* (2000), 83–90. 1

[Léc09] LÉCUYER A.: Simulting haptic feedback using vision: A survey of research and applications of pseudo-haptic feedback. *Teleoperators and Virtual Environments 18*, 1 (2009), 39–53. 3

[MEBR99] MRRRAY D., ELLIS R., BANDOMIR C., ROSS H.: Charpentier (1891) on the size-weight illusion. perception and psychophysics, 61 (8). *Attention, Perception, & Psychophysics 61*, 8 (1999), 1681–1685. 2

[MS94] MASSIE T., SALISBURY J.: The phantom haptic interface: A device for probing virtual objects. In *Proceedings of the ASME winter annual meeting, symposium on haptic interfaces for virtual environment and teleoperator systems* (1994), vol. 55, pp. 295–300. 1

[NKO07] NAKAHARA M., KITAHARA I., OHTA Y.: Sensory propety in fusion of visual/haptic cues by using mixed reality. *Second Joint Eurohaptics Conference and Symposium on Haptic Interfaces For Virtual Environment and Teleoperator System* (2007). 3

[PC] 'powercursor' http://www.powercursor.com/. 3

[PMC09] PUSCH A., MARTIN O., COQUILLART S.: Hemp–hand-displacement-based pseudo-haptics: A study of a force field application and a behavioural analysis. *International Journal of Human-Computer Studies 67*, 3 (2009), 256–268. 3

[RV64] ROCK I., VICTOR J.: Vision and touch: An experimentally created conflict the two senses. *Science 143* (1964), 595–569. 3

[STJ06] S S., T M., J W.: Image deformation using moving least squares. *ACM Transactions on Graphics 25*, 3 (2006), 533–540. 4, 5

[vM02] VAN MENSVOORT K.: What you see is what you feel: exploiting the dominance of the visual over the haptic domain to simulate force-feedback with cursor displacements. *Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods and techniques* (2002), 345–348. 3