Displaying Deformation of Virtual Objects Using Visuo-Haptic Interaction

Yuki Ban[1]

[1] Graduate School of Frontier Sciences, The University of Tokyo
Keywords: Visuo-haptic Interaction, Object Deforming, Virtual Reality,

ABSTRACT

We developed the visuo-haptic shape display system with which users can deform virtual objects dynamically. Our system senses how the force is applied to the grasping object, and deforms the virtual grasping object and the virtual hands according to the direction and size of the force.

1 INTRODUCTION

Various researchers have developed the technique which presents the sense of touching the virtual object in the virtual environment (VE), and they are roughly divided into two approaches. One is a technique called "active haptics" which physically reproduces the force directly using robot arms, deformable displays, exoskeletal devices, etc.. The other is a technique called "passive haptics" which physically prepares alternative tactile presentation objects and presents tactile sensation by synchronizing them with contact events in VE. "Passive haptics" does not require the use of complicated and expensive force presentation equipment, and the equipment mounting cost to the user is also low, compared with "active haptics" which physically reproduces the 100% accurate force, so it has the advantage that the tactile force presentation with high expressiveness is more convenient. In addition, in these "passive haptics" techniques, by visually transforming and presenting the position of an object and the movement of a user's hand and arm, an attempt has been made to realize various tactile experiences by manipulating the perception of the position and shape of a virtual object, although an object which is not actually deformed in a fixed shape is touched.

For example, M. Azmandian et al. have developed a method of visually distorting and presenting the position of an object and the movement of the hand of a user approaching it, so that the user can feel as if he or she is manipulating many boxes, even though only one box is actually moving [1]. In our previous research, we modified the perception of the shape of object we are touching by transforming the movement and posture of the user's visual hand to fit to the virtual object, although actually the user touches an actual object which shape is different from the virtual object [2].

In addition, in the "passive haptics" technique, it has been clarified that the perception to the hard and soft feeling of the object can be also modified by measuring the force which the user applies to the grasping object and

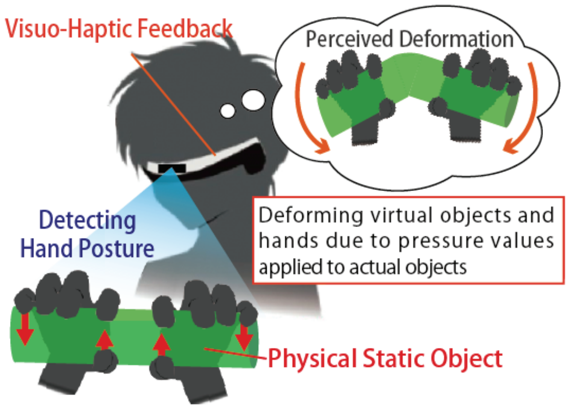

Fig. 1 Concept of display of deforming virtual object using visuo-haptic feedback.

visually deforming the shape of the virtual object in proportion to it [3]. However, in these techniques, the deforming perception operation in the pressing direction is main, and the feeling to bend and twist the object has not been realized. In addition, in the deformation presentation of the virtual object, the illusion improvement effect by the presentation of the virtual hand has not been confirmed. It has been clarified that, when shape perception for virtual objects is changed, not only virtual objects different from actual shapes are visually presented, but also the effect of shape perception operation is enhanced by presenting virtual hands which touch them together. However, in this method, only the effect by the movement amount operation of the virtual hand in the three axial directions has been confirmed, and the modulation of the movement in the rotational direction for the operation to twist or bend the object has not been realized. The visuo-haptic interaction for the rotational direction has been confirmed in the situation in which the operation part and the display part are separated [4], however, it is difficult for the virtual hand operation to identify the position of both hands in contact with the object and to modulate the posture including the rotation of wrist and elbow. Furthermore, the visuo-haptic interaction using both hands has not been realized, because of the difficulty of spatial consistency maintenance between contact points after modulation.

Thus, the purpose of this study is to extend the effect of the visuo-haptic interaction to 6-axial object manipulation with both hands, and to realize a visual haptic display which can manipulate deep sensation in dynamic object deformation using both hands (Fig. 1). As mentioned above, the visuo-haptic interaction using conventional virtual hands can only modulate a fixed object's shape with three axial degrees of freedom because of the difficulty of natural posture modulation. This study extends this method and aims to realize the visuo-haptic display system which can present sense of deforming virtual objects.

2 RELATED WORKS

While much research dealt with cross-modal effects between hap- tic sensations and other sensations, we mainly focused on effects between haptic sensations and vision. Some studies reported that visual stimuli affect the tactile sense. They also studied the cognitive features of the object's deformation and the stiffness of an object, such as the difference threshold and the perception mechanism [5]. Srinivasan et al. revealed that, when we are presented with conflicting sensory stimuli, vision usually dominates in our perception of stiffness.

These studies associated the visual stimuli to the physical haptic device, while other studies focused on influencing the perceived stiffness using visual feedback and a physically static device or object. Pseudo-haptics, which describes the illusion triggered by this characteristic, was first introduced by Lecuyer [6]. This phenomenon is induced when an inconsistency occurs between the actual body motion and the projected motion. Lecuyer et al. had participants push their thumbs against a piston, which in turn pushed against an isometric Spaceball device. Simultaneously, participants were visually presented with a compressed virtual spring. Even though the Spaceball device was not compressed, the virtual spring deformed visually and influenced the participants' perception of stiffness.

Hirano et al. investigated the power of influence of visual feedback on deforming the virtual object using mixed reality technology [7]. They superimposed a computer graphics (CG) object on the real object and controlled the amount of deformation of the CG object as a function of the pressure with which the users pushed the object. The participants felt different levels of stiffness from the real object depending on the deformation of the CG objects. Kimura et al. studied the control of perception of softness by grasping the object [8]. They asked participants to grasp a physically static mobile device and showed them a virtual rectangle which deformed as a function of the squeezing force on the device's screen. The participants' perception of softness was influenced by the amount of deformation of the displayed rectangle. We also have developed the system which deforms virtual object due to the force of pinching actual object with one hand, and also deform virtual hand's posture to fit to the crushed virtual object [3]. We revealed that displaying virtual hand which posture is deformed plays a role to enhance the sense of deforming virtual objects. Besides, Paljic et al. has revealed the effect of pseudo-haptics for simulating torque [4]. In their experiment, a participant twisted an actual handle with one hand, and their system visually modified the rotation amount of this handle to modulate the stiffness sensation of the virtual handle.

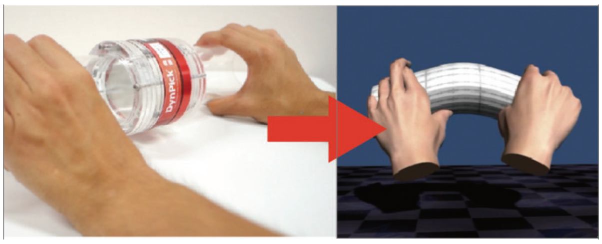

Fig. 2 6-axis force sensor mounted on the cylindrical physically static object (left), and the virtual object and hands as the visual feedback displayed on the HMD.

3 CONCEPT and IMPLIMENTATION

As we described above, several researchers have developed the systems which display deformable virtual objects with various stiffness. However, all of them used an actual deformable object to display virtual one, and few of them tried to display virtual deformable object with an actual static object. Moreover, their systems only supports one-handed object manipulation with particular one direction, and has not realized the interaction of deforming objects with both hands.

Thus, in this study, we aims to realize the visuo-haptic display system which can present sense of deforming virtual objects with various direction using two hands (Fig. 1). Because of the difficulty of natural posture modulation, conventional pseudo-haptics with virtual hands can only modulate with three axial degrees of freedom by tracing an object fixed in space. In this study, we extend this method and aim to realize the visuo-haptic interaction for virtual hands with high degrees of freedom that take into account the direction of rotation by using a depth camera to perform hand posture recognition and manipulation more precisely. In this way, we realize the technique which can be made to perceive as if the virtual object is being deformed, even if the object which is not actually deformed is grasped. To enhance the effect of the visuo-haptic interaction, we also tried to present virtual hand which posture is deformed to fit to the virtual object.

3.1 System Configuration

This system was composed of an object mounted with a 6-axis sensor to measure load force, a Head Mounted Display (HMD), and a depth camera. We used Oculus Rift (Oculus Inc.) as an HMD, and Leap Motion (LEAP MOTION Inc.) as an depth camera. This depth camera was mounted on the front of the HMD. Through the HMD, users watch virtual object and their virtual hands which grasp and deform a virtual object (Fig. 2 right). To

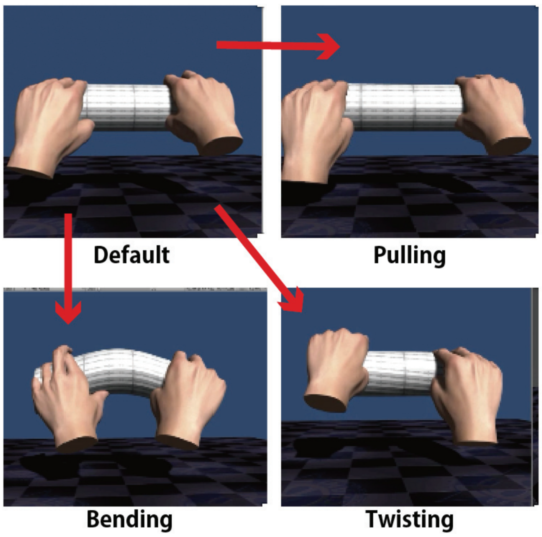

Fig. 3 Visual feedback of deforming the virtual object and hands in three directions.

measure the direction and magnitude of the grasping force on an object, a cylindrical grasped object equipped with a capacitive six-axis force sensor (DynPick, Wacoh-Tech Inc.) was constructed as shown in Fig. 2 left. This sensor can measure the magnitude of the force around 6 axes on the objects fx, fy, fz [N], mx, my, mz [N m]. And, because the relative position of both hands to the object was fixed in the system, the grasped object's angle and the position of the center of gravity were calculated from the positional relation of the hand recognized from the depth sensor, and were reflected to the virtual object. Concretely, the center of gravity of both hands was connected by a line segment, and the center point of this line segment was made to be the center of gravity of the cylindrical grasping virtual object, and this line segment and the axis of the virtual object were made to be parallel.

3.2 Algorithm of Deforming Virtual Object and Hand

Next, we described an algorithm to deform a virtual object using the values measured by a six-axis force sensor. First, the direction of bending, stretching, and twisting is judged from the 6-axis force sensor. The virtual object is then deformed according to the magnitude of the applied force. By adjusting the amount of deformation according to the input size, it is possible to manipulate the perception of the hardness of virtual objects. In addition, by modulating the position and posture of the virtual hand so as to match the amount of deformation of the position holding the virtual object and the change of the angle in the axial direction, visual feedback such as holding and transforming the deformed virtual object was realized (Fig. 4). Though the research which tried to present deformation sensation by the interaction between visual sense and tactile sense is few, it has been confirmed that it is made to perceive that virtual object is touched by the effect of visual feedback, even if size and width of the object shape are about ± 30% and angles of angular surface are about ± 30 degrees different from the real object [2, 9].

Therefore, we hypothesized that the effect of the interaction between visual sense and tactile sense could be generated even in this study up to the deformation of the largest degree. The maximum value of the virtual object deformation quantity was set at ± 0.35 times of the length direction of the cylindrical shape on the pulling and pushing direction, and at 35 degrees of both labor and labor on the bending and twisting.

Fig. 3 shows the visual feedback using this algorithm. By deforming both of virtual object and hand, the system could generate a natural feedback image for the three direction deformation motion of tension, bending, and torsion.

4 BRIEF USER STUDY

4.1 Overview

Using the constructed virtual object and hand deformation algorithm, we verified whether the sense in which the virtual object was deformed could be presented in spite of grasping the object which is not actually deformed. The experiment was conducted on 10 participants (22 ~ 25 years old, 3 women, 7 men). In this user study, by presenting virtual hardness by various manipulations of deformation quantity when force was applied, how the reality perceived at deformation changed was verified.

4.2 Task Design

In this experiment, an acrylic cylinder with a length of 300 [mm] and a diameter of 60 [mm], in which a force sensor was incorporated, was subjected to 3 directions of tension, bending and torsion. For the amount of deformation when force was applied, three levels of hardness of 0.2, 0.4, and 0.8 [N/mm] were set for the tensile direction, and 95.6, 144, and 287 [N/rad] for the bending and torsion, and the reality of the feeling of deformation when force was applied was answered in 7 levels evaluation (1: No reality at all, 7 Definitely real). The number of trials was 8, one for each combination of hardness and force direction. The order of trials was balanced among participants.

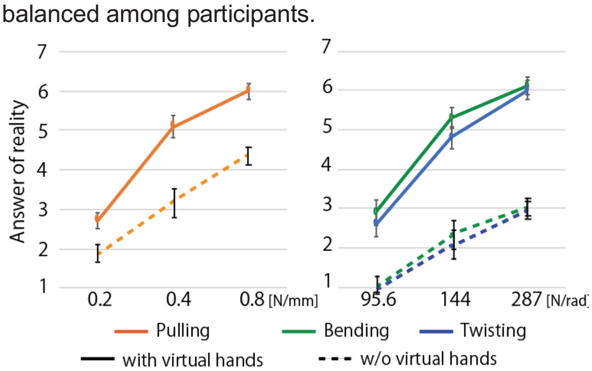

Fig. 4 Result of the user study.

4.3 Result and Discussion

Fig. 4 shows the evaluation of reality for each hardness and force direction trial (average, standard error). From this result, it was confirmed that the harder the presented hardness is, the higher the perceived reality is. Besides it was also confirmed that the perceived reality rapidly decreases when the virtual hardness falls below a certain value. Concretely, when the results under 0.2 N/mm and 0.4 N/mm conditions of the tension task were compared, the answer that there was no reality became very strong with average of 2.7 under 0.2 N/mm condition, in spite of comparatively high evaluation value of 5.1 under 0.4 N/mm condition. A similar trend appeared in the bending direction results.

Besides, it was also confirmed that even if the amount of visual feedback manipulation is the same, that is, the deformation angle is the same, the perceived reality between the bending task and the torsion task is different. It is considered that this is because the amount of change perceived visually in the bending direction is larger than that in the torsion direction. Therefore, in the future, it is necessary to verify how the perception for the reality of the feeling of deformation changes by making the texture of the grasped object to be easy to confirm the deformation and by not presenting the virtual hand which is grasped.

5 CONCLUSIONS

In this study, we propose a method to present the sensation of deforming a virtual object in various directions in spite of holding a static object which is not actually deformed using the effect of the visuo-haptic interaction. A 6-axis force sensor which can sense the direction and magnitude of the load force is built in the grasping object, and the effect of visuo-haptic interaction is generated by deforming the virtual object and the virtual hand which grasps it according to the measured force.

As a result of the user study, it was shown that the generation of the interaction between visual sense and tactile sense by the presentation of the virtual hand was useful in the presentation of the deformation sensation of the virtual object, and it was indicated that the visual presentation of the degree of deformation effectively was important for the illusion generation. As the future study, we will verify in more detail how virtual hardness, maximum deformation, texture of virtual object surface, presentation of virtual hand, and so on affect reality of deformation sensation.

6 ACKNOWLEDGEMENT

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Early-Career Scientists, 19K20315, 2019.

REFERENCES

[1] Azmandian, M. et al.: Haptic retargeting: Dynamic repurposing of passive haptics for enhanced virtual reality experiences. In Proc. of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1968-1979 (2016).

[2] Ban, Y. et al.: Modifying an identified angle of edged shapes using pseudo-haptic effects. EuroHaptics, pp. 25-36 (2012).

[3] Ban, Y. et al. Controlling perceived stiffness of pinched objects using visual feed- back of hand deformation. In Haptics Symposium (HAPTICS). pp. 557-562 (2014).

[4] Paljic et al. Evaluation of pseudo-haptic feedback for simulating torque, HAPTICS, pp. 216-223 (2004).

[5] Tachi, S. et al. Construction Method of Virtual Haptic Space. In Proceedings of the 4th International Conference on Artificial Reality and Tele- Existence, pp.131–138 (1994).

[6] A. Le´cuyer. Simulting haptic feedback using vision: A survey of research and applications of pseudo-haptic feedback. Teleoperators and Virtual Environments, 18(1):39–53 (2009)

[7] Y. Hirano, et al., Psychophysical influence of mixed-reality visual stimulation on sense of hardness. Virtual Reality Conference (VR), 2011 IEEE, pp. 51–54 (2011).

[8] T. Kimura et al. Pseudo-haptic feedback on softness induced by grasping motion. proceedings of EuroHaptics, 2:202–205 (2012).

[9] Y. Ban et al. Modifying an identified curved surface shape using pseudo-haptic effect. In Haptics Symposium (HAPTICS), pp. 211-216 (2012).