Altering Resistive Force Perception by Modulating Velocity of Dot Pattern Projected onto Hand

Sota Aoyama
Osaka University
Graduate School of
Engineering Science
aoyama@sens.sys.es.osaka-u.ac.jp

Daisuke Iwai
Osaka University
Graduate School of
Engineering Science
daisuke.iwai@sys.es.osaka-u.ac.jp

Kosuke Sato
Osaka University
Graduate School of
Engineering Science
sato@sys.es.osaka-u.ac.jp

ABSTRACT

In this paper, we explore the possibility of altering user's resistive force perception by using pseudo-haptics in spatial augmented reality. Through a psychophysical experiment, we investigated the effect of changing the velocity of a dot pattern projected onto a participant's hand during the resistive force perception. A statistical analysis of the result reveals that the speed of the dot pattern movement affects the perceived force such that a faster movement makes participants feel a smaller force, and the direction of the movement has no effect.

CCS Concepts

•Computing methodologies → Mixed / augmented reality; Perception;

Keywords

Pseudo-haptics, spatial augmented reality, projection mapping, resistive force perception

1. INTRODUCTION

In recent augmented reality (AR) research, a type of pseudo-haptics (PH) feedback, known as the cross-modal effect, has been intensively investigated. PH feedback is a haptic illusion triggered by a property of the human brain that arises from the inconsistency between visual information and haptic information. PH feedback shows great potential for generating various types of haptic feedback using visual information without the need for the user to wear any complex haptic devices [2]. In an AR environment, it is well known that using PH feedback can manipulate force, shape, or thermal perception [1] [4] [5] [6] [8] [9]. However, the scope of PH feedback in AR research has been limited to video see-through AR that can control the visual information of a real scene. To date, spatial AR (SAR) has not been a research focus.

SAR can alter the appearance of a real object, including its color, shape, or surface texture, by projecting computer graphics onto it without using a display device. However, when we use a haptic device to present haptic feedback, SAR loses this advantage. Accordingly, we have focused on PH feedback and tried to manipulate human perception in an SAR environment [1] [5]. In this paper, we explore resistive force perception as an example of haptic perception and define the reverse direction force as the resistive force.

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2. RELATED WORK

PH feedback is caused by the multi sensory integration of visual and haptic sensations in the human brain. Following the pioneering work by Lecuyer et al. [3] [4], several studies on virtual reality (VR) systems have implemented PH feedback, which presents haptic and tactile sensations by providing visual information that causes inconsistency between visual and haptic sensations [2]. Sensory inconsistencies can be presented with relative ease in VR environments because the graphics of the virtual objects are completely controllable. Recently, PH feedback was also observed to occur in video see-through AR environments, where user's bodies or real objects are visually modified and presented [6]. However, to date, SAR has not been a research focus.

The alteration of the resistive force perception using PH feedback has been investigated in both VR and AR research. Pusch et al. found that modulating the velocity of a virtual hand that users control via a head-mounted display (HMD) can provide a pseudo resistive force for users [6]. Ban et al. found that in the touch panel system, changing the control/display ratio of a user's finger walking can provide PH feedback [8]. Watanabe et al. found that changing the speed of a background object on a PC monitor in which a user is controlling a cursor generates PH feedback that is similar to a collision force [9].

These studies suggest that there is a possibility of altering a user's force perception by modulating the velocity or movement of objects that a user controls. However, the alteration is limited whithin the display's field-of-view or it requires users to wear physical equipment such as an HMD because most previous studies about PH feedback only focus on video see-through AR.

To solve these limitations, we provide visual information in projection-based MR that enables a wide field of view

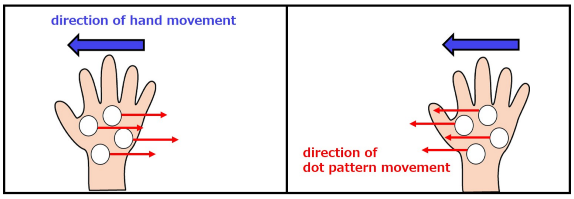

Figure 1: Direction of the dot pattern movement (left) backward and (right) forward directions

and does not require hand-held or body-worn devices. Although conventional SAR environments are able to visualize the surface appearance of different materials within physical objects, they are still limited with respect to controlling the visual properties of surface materials. To control the haptic feedback of a physical object, our research group has already successfully constructed a PH feedback system for SAR that can create perceptions such as those of softness or thermal properties [1] [5].

3. PROPOSED METHOD

In our research, we modulate velocity to alter resistive force perception, similar to the related works [6] [8] [9]. However, it is more difficult to modulate the velocity of a target (i.e., the objects a user controls or user's hand) in the real world (with SAR) than in the virtual world (using video see-through MR). As one simple example, we consider the projection of a modulated velocity image onto the real world. In this method, there is the double image of the real hand and projected hand image; thus, it is difficult to generate PH.

Our research group has succeeded in constructing a PH system in SAR to manipulate surface softness perception by projecting a two dimensional dent deformation on an object's surface and changing the appearance of the user's hand [5]. Ho et al. found that changing the user's hand color to blue or red by projection, affected the user's thermal perception [1]. These studies suggest the possibility of altering a user's perception by changing the appearance of body by projecting a texture in SAR. Hence, we investigated whether users feel as if the velocity of their operational object (the hand in our research) has been modulated by changing its appearance in projection-based MR, and we propose a method to generate PH for altering resistive force perception.

Specifically, we use a (spatially random) dot pattern as the texture projected onto a user's hand. We then make the dot pattern move on the user's hand synchronously with the hand movement, and we modulate the dot pattern's relative velocity such that it is slower or faster than the hand. Using this method, users perceive that their hand's velocity has been modulated, and as a result, PH is generated by producing an inconsistency between the user's visual and haptic sensations. In our research, we modulated the dot pattern's velocity, which is separated into a speed and direction component. We then considerd the following hypotheses.

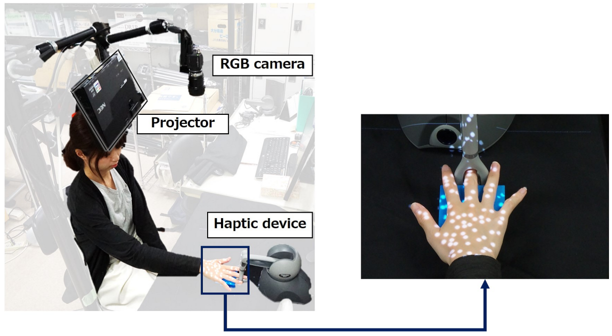

Figure 2: System configuration

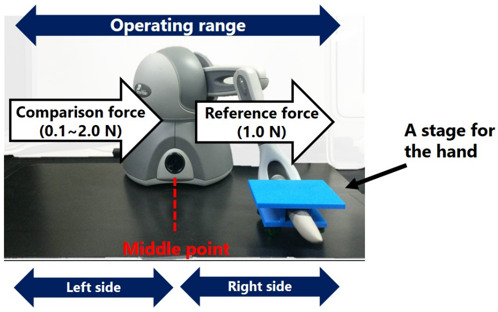

Figure 3: Operating range of the haptic device resistive force for the comparison task

1. Modulation of the dot pattern's direction (forward or backward in Fig. 1) affects the user's resistive force perception. In the forward condition, the user perceives a smaller force, and in the backward condition, a larger force is perceived.
2. Modulation of the dot pattern's speed (fast or slow) affects the user's resistive force perception. In the fast condition, the user perceives a smaller force, and in the slow condition, a larger force is perceived.

4. EXPERIMENT

This section describes the experiment to evaluate the hypotheses. In this experiment, since the haptic rendering of accurate forces is important we used a haptic device to provide the real resistive force for participants. We then investigated whether the resistive force that participants perceived was changed by a comparison task.

4.1 Experimental system

Figure 2 shows the configuration of the experimental system. This system comprises an RGB camera for detecting the hand, a projector for projecting the dot pattern, and a haptic device for providing resistive force. The RGB camera and projector are placed above the participant, and the haptic device is placed in front of the participant. In this experiment, we define the "right side", "left side", and "middle point" as in figure 3.

4.2 Comparison task

In the experiment, we asked participants to perform a comparison task. Participants compared the two resistive forces provided by the haptic device in this task (Fig. 3). The procedure was as follows. First, participants moved

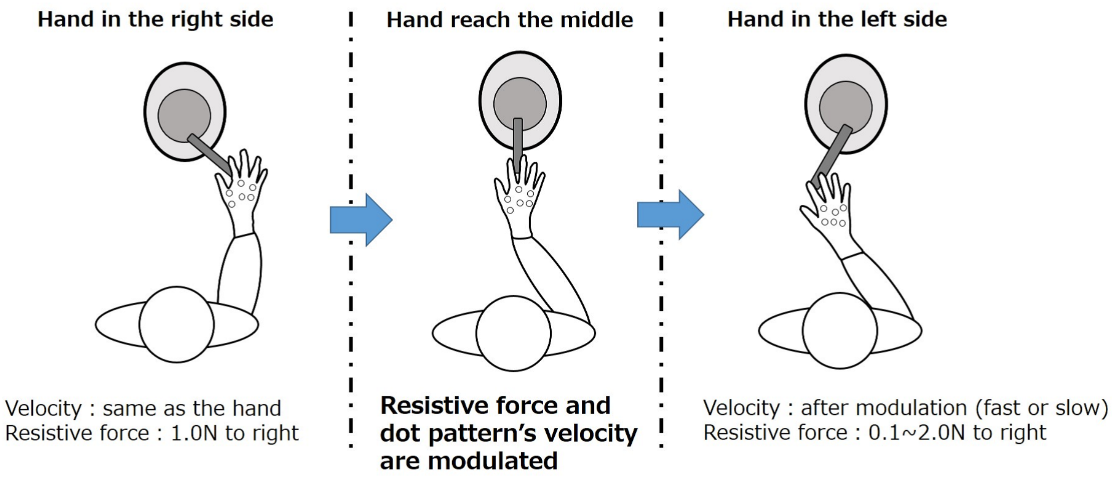

Figure 4: Procedure of modulating dot pattern's velocity and resistive force

their hand on the stage connected to the haptic device from the right side to the left. The haptic device provides the resistive force of 1.0 N as a reference force when the participant's hand moves from the right side to the middle point. Then, it changes the force to a comparison force. After the hand movement, they compared the reference force and comparison force. Finally, they answered whether the comparison force was smaller or larger than the reference force.

In this task, we instructed them to move their hand at a constant velocity and allowed them to retry till they could answer. The force that the haptic device provides is toward the right, and the comparison force is varied from 0.1 to 2.0 N) according to the parameter estimation by sequential testing (PEST) method [7]. Using this method, we estimated the threshold at which participants perceived a larger force level than the reference force.

PEST method

The comparison force is determined by the PEST method as follows.

- The next force level decreases if the participant answers "larger" for the current force level, and vice versa.
- The variation width is halved if the participant changes his/her answer from that of the previous comparison task.
- The variation width is doubled if the participant answers the same more than three times.
- The comparison task is complete when the variation width falls below a predefined value.

We let participants do two blocks per each visual stimulus. In one block, initial comparison force was randomly selected from 0.1 to 0.3 N, and in the other block, it was randomly selected from 1.8 to 2.0 N. One block consists of one-time PEST method.

Visual stimulus

In the experiment, we used the dot pattern's relative velocity with respect to the hand (speed and direction) as the parameters of the visual stimulus. As in the figure 4, the dot pattern's velocity is the same as that of the hand (the appearance of the hand is unchanged) when the hand is moved in the right side (reference force range). Next, the dot pattern's velocity is modulated when the hand is moved from the middle to left side (comparison force range). We prepared eight conditions for the visual stimulus. The first six conditions are the combinations of three dot pattern directions (forward, backward, and towards the fingertip), and two dot pattern speeds (fast and slow). The fingertip direction is the direction in which the participants faces. The fast and slow speed conditions were 63.0 mm/s and 31.5 mm/s, respectively. In addition to these visual stimuli, a condition in which no dot pattern was projected (no projection) and a condition in which the dot pattern's speed was not modulated (no modulation) form the final two conditions.

4.3 Results

In the experiment, there were 12 participants, and we analyzed the average of the threshold estimated by PEST method for all participants for all eight conditions. Figure 5 shows that the two thresholds are almost the same in the "no projection" and "no modulation" conditions. Therefore, from this, we can conclude that the "no modulation" condition has no effect on their resistive force perception. Furthermore, the fact that the two values are close to reference force level (1.0 N) shows that participants compared the forces accurately. Figure 6 shows the average of the thresholds for six conditions (combinations of speed and direction). We applied a two-way factorial analysis of variance (ANOVA) for speed and direction. The analysis shows that there is a significant difference for dot pattern speed but no significant difference for dot pattern direction ($p < 0.01$). Figure 7 shows the results of the one-way ANOVA for the "fast", "slow", and "no modulation" groups for different direction. This analysis shows that there are only significant differences between "fast" and the other two groups ($p < 0.05$).

These results and analysis confirm that a dot pattern's relative velocity modulation has an effect on resistive force perception. Specifically, the fast dot pattern movement caused

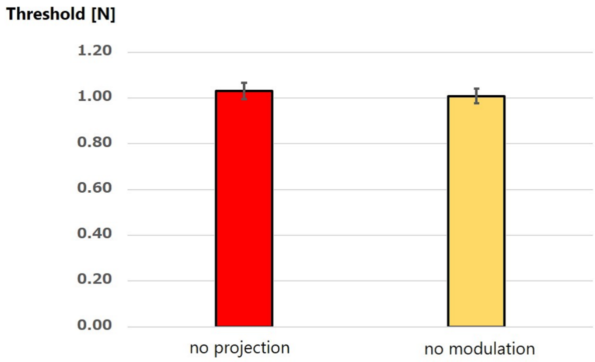

Figure 5: Result of "no projection" and "no modulation"

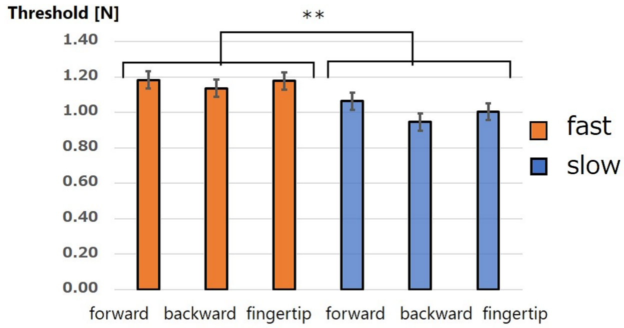

Figure 6: Result of modulation of speed and direction (: $p < 0.01$)**

participants to perceive a force is approximately 0.2 N smaller than any other condition. These results reveal that hypotheses 1 is not supported, but hypotheses 2 is supported.

5. CONCLUSION

In this paper, we explored the possibility of altering user's force perception using PH in projection-based mixed reality. To achieve this objective, we conducted a psychophysical experiment that investigated whether the velocity changes of dot patterns projected on a participant's hand affected resistive force perception. The experimental results and analysis suggest that the speed of the dot pattern movement affects the perceived force. Specifically, faster movement makes participants perceive a smaller force. However, we still do not understand the mechanism under which the participants perceived smaller forces regardless of the directions of the dot patterns. In addition, we did not find any visual effects by which the participants perceived larger forces than the actual ones. We will conduct further experiments to investigate these issues with other types of visual stimulus.

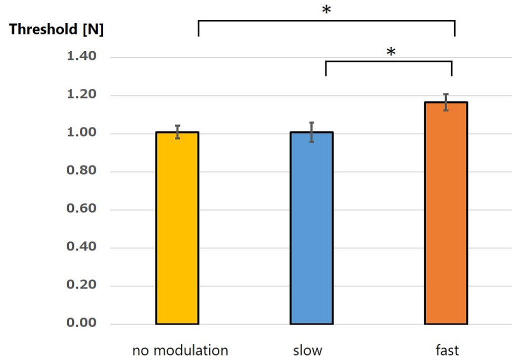

Figure 7: Result of differences in the speed (*: $p < 0.05$)

6. ACKNOWLEDGMENTS

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