Enhancement of Motion Sensation by Pulling Clothes

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ABSTRACT

Stimulation of the vestibular and somatosensory systems has been proposed as a way to enhance motion sensation in combination with visual movement. However, such systems may be large with limited presentation areas. Here, we propose a method of enhancing motion sensation by pulling clothing. Our system uses DC motors and force sensors to present traction force and cause skin deformation. We investigated whether users perceived the presented sensation as acceleration, or another physical quantity, and found that they matched it with velocity. We also conducted a user study to see whether immersion of gaming contents could be improved by our clothes-pulling system.

Keywords

Haptic; Tactile; Clothes-pulling;

1. INTRODUCTION

In audiovisual content with self-motion, such as a racing game, successful presentation of the sense of motion is considered to be the key to realism. The sense of motion is a multisensory event, as it includes velocity information from the visual system and acceleration information from the vestibular and somatosensory systems. Various entertainment facilities incorporate stimulation of the vestibular and somatosensory systems by actually moving the user's body in accordance with the presented motion [7][12]. However, such devices tend to be bulky and expensive, which makes them difficult for home use.

One solution to this issue involves the use of somatosensory cues. For instance, several studies have investigated the effects of chairs that vibrate in accordance with visual contents [1][4][10]. Danieau [3] used haptic devices to shake the body parts of a user sitting on a seat. In addition, many haptic devices that present force feedback to the hands of users have been reported [2][5][9]. All of these devices succeeded in inducing the sense of motion, using only haptic sensations.

In this study, we tested a method of eliciting self-motion by pulling on the clothing of participants while they sat on a chair. Clothing generally touches a wide area of skin. Therefore, pulling on clothing may induce haptic and/or force sensations over a wide region of the body. Pulling on clothing is expected to produce traction force that could create the illusion of dramatic movement in the users' body. Furthermore, the shearing force between the skin and cloth could generate shearing skin deformation, which has been proposed as a cue for pseudo force [6][11]. Therefore, we hypothesized that these sensations could be used to enhance the perception of self-motion, for example, when a car is rapidly accelerated.

In this paper, we describe our clothes-pulling system, which uses DC motors and force sensors. We conducted a user study to assess whether users perceived the presented sensations as acceleration, or as another physical event. We also examined the overall influence of the clothes-pulling system on user experience.

2. SYSTEM

Figure 1 shows the clothes-pulling system. It is composed of a chair with a backrest, motors with a gear head (Maxon, 25 RE φ 25mm, 10W, 26 GP B φ26 mm, gear ratio 19:1), motor drivers (Okatech, JW-143-2), bobbins, guides, Kevlar string, clips, a microcontroller (NXP, mbed NXP LPC1768), load cells (A&D, LC-1205-K020) and amplifiers (A&D, AD-4532B).

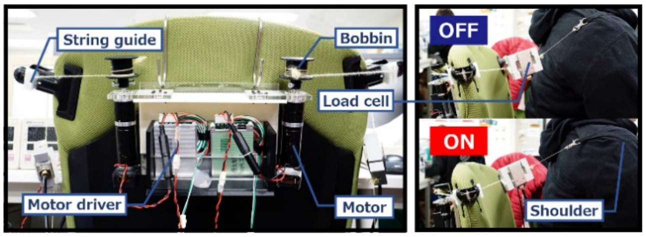

Figure 1. The clothes-pulling system

The clips with string are attached to the shoulder part of the user's clothes. By attaching the clips to the shoulder, the system can effectively pull the upper body backward. Using motors to reel in the string, the system pulls the clothing and presents a traction force. The motors are current-controlled by the microcontroller. The two motors correspond to the left and right shoulders, each of which can provide force of up to about 18N. In the initial state, traction of about 2N is presented to the body by weight of the load cell (0.3 kg). The traction force is measured by the load cells and controlled using proportional-derivative control (PD control).

3. HARDWARE EVALUATION

We considered that the device might not induce a traction force on the body based solely on the friction between the string and the

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guide. Thus, we directly measured the traction force using the load cells and controlled the force using a PD controller.

In Equation 1, I represents the electrical current delivered to the motor, k_P represents the coefficient for the proportional term, k_D represents the coefficient for the differential term, F_g represents the desired traction force, F represents the current traction force, and F_b represents the traction force of the previous frame.

$$\boldsymbol{I = k_P \times (F_g - F) - k_D \times (F - F_b)} \qquad (1)$$

3.1 Motor Traction

Figure 2 shows the traction of one motor with and without PD feedback. The feedback loop was set to 1 kHz. When the feedback was not applied, the traction force was typically lower than the designated value, mainly because of friction. When the feedback was applied, the traction force was in agreement with the designated value.

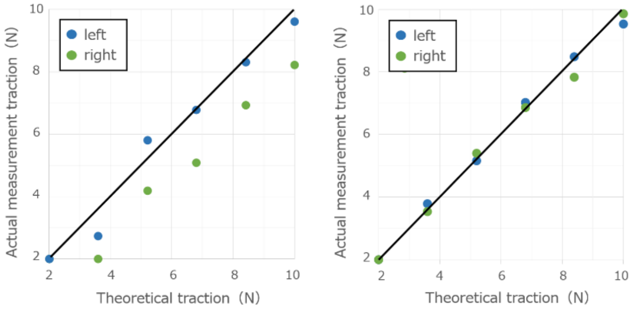

Figure 2. Traction of one motor without (left) and with PD feedback (right)

3.2 Motor Response

Figure 3 shows the response of one motor when we applied a 10 s step function with different designated values. The response time was about 0.16, 0.21, and 0.24 s when the designated traction force was 10, 14, and 18 N, respectively.

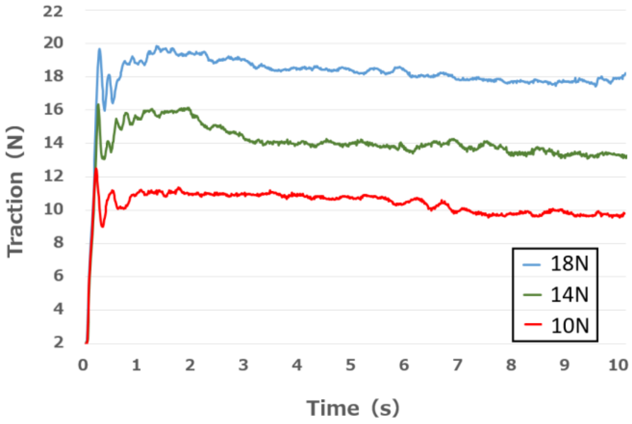

Figure 3. Response of one motor

4. EXPERIMENT 1: CORRESPONDENCE TO PHYSICAL QUANTITY

As the purpose of this study was to present the sense of motion, we found it necessary to consider the different types of motion. The physical quantity of motion has three aspects: position, velocity and acceleration. We wanted to identify the physical quantity that users felt or interpreted when our system presented as traction force.

Position, velocity, and acceleration are related by derivatives and integrals. If position is represented by a sine wave, then velocity and acceleration can also be represented as sine waves with phase differences of $1/2\pi$ and π relative to the sine wave of position. We used these properties to evaluate the subjective feeling elicited by our system.

4.1 Methods

Participants were exposed to an optical flow stimulus that moved forward and backward in a sinusoidal manner. Figure 4 shows the visual stimuli, which was rendered using Unity software (Unity Technologies, Inc.) and presented using a head-mounted display (HMD) (Oculus VR Inc., Oculus Rift Development Kit 2, resolution 1920 × 1080 (one eye 960 × 1080), horizontal angle of 90 °, diagonal angle of 110 °). To make the maximum speed of movement 60km/h, the point of view was moved back and forth according to a sine wave at 0.1 Hz. In addition, a fixation point was positioned in the center of the visual stimuli.

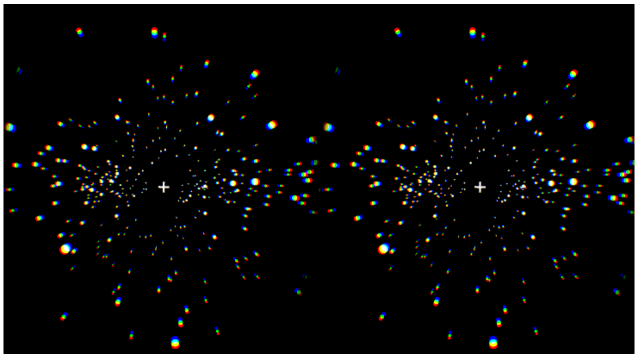

Figure 4. Visual stimuli (left: view of left eye, right: view of right eye)

We also presented a traction force, which changed according to a sinusoidal wave. However, the negative component of the wave could not be presented owing to system limitations. The sinusoidal traction force had a frequency of about 0.1 Hz, and ranged from about 2N (initial state) to about 18N, in accordance with the visual stimuli.

To control the clothing type and to facilitate the ease of attachment of the system clips, the participants all wore a hooded sweatshirt. They were instructed to sit on the chair that housed the clothes-pulling system, and to wear the HMD and noise canceling headphones (BOSE, QuietComfort15). We asked them to adjust the phase of the traction force to match the feeling between the visual motion and the traction force. If the phase difference between the sine wave of the visual stimuli and the sine wave of the traction force was close to 0, then the traction force was interpreted as positional displacement. If the phase difference was close to 1/2π, then the force was interpreted as velocity. If it was close to π, then it was interpreted as acceleration (Figure 5). Twelve participants, 21–25 years of age, participated in this experiment. Five trials were carried out for each participant.

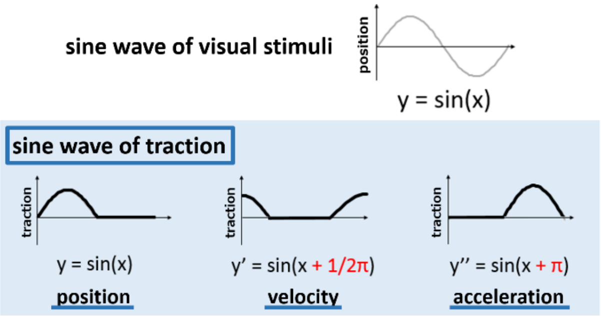

Figure 5. Three physical properties according to differences in sine wave phase

4.2 Results and Discussion

Figure 6 shows the sine wave phase difference between the visual stimuli and traction force. More than 80% of the participants answered that the difference in the sine wave phase between the visual stimuli and traction was approximately $1/2\pi$. This means that they felt that the traction was well matched with the visual stimuli when the traction force was proportional to the velocity of the visual stimuli.

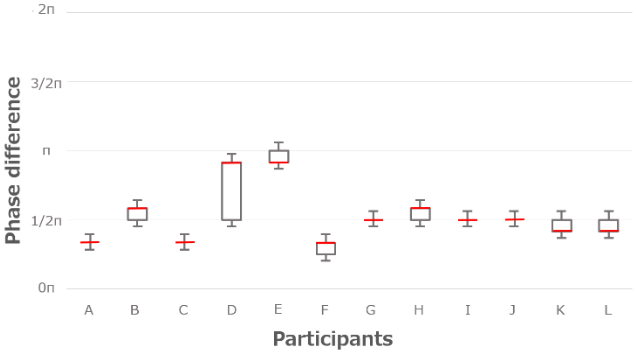

Figure 6. Difference in sine wave phase between visual stimuli and traction

According to basic physical properties, we hypothesized that the traction force produced by our system would be interpreted as acceleration ($F = ma$). However, most participants interpreted the traction force as velocity. It may be easier to perceive velocity, rather than acceleration, from visual stimuli. For example, when watching the scenery from the window of a moving car, it is possible to estimate the velocity at which one is travelling. However, estimating the acceleration is difficult in comparison. That the participants were able to adjust the traction force in accordance with visual stimuli may also have contributed to the tendency to interpret the traction force in our system as velocity.

5. EXPERIMENT 2: INFLUENCE ON USER EXPERIENCE

The result of Experiment 1 indicated that, for content with visual movement, the traction force should be presented in accordance with velocity. Based on this result, we investigated whether the immersion of content was improved by our system.

5.1 Methods

We prepared a simplified car driving simulation in which the point of view moved forwards when the user pedaled. Figure 7 shows the visual stimuli, which was rendered using Unity and presented via a HMD. In the visual stimuli, the height of the point of view was 1.2 m, and the road width was 4 m. Trees, 8 meters in height, were positioned at 10 m intervals. The maximum velocity was 180km/h. The point of view was accelerated according to the amount of depression of a pedal (Logicool, Logicool® Driving Force™ GT).

Figure 7. Visual stimuli

We also presented a traction force in accordance with the velocity. As the velocity of the visual stimuli increased, the traction force became stronger in proportion. In this experiment, we used a simple clothes-pulling system without the load cells.

Each participant sat on the chair that housed the clothes-pulling system, wearing a hooded sweatshirt and the noise canceling headphones. We presented the visual stimuli twice for three minutes each, once with and once without the system (*Traction*, *No Traction*). The order of the two conditions was counterbalanced. After each condition, the participants answered questions on a 7-point Likert scale (1: very weak – 4: neutral – 7: very strong). They were asked to rate their feelings of movement, speed, acceleration, immersion, and enjoyment for each condition. We administered the Simulator Sickness Questionnaire (SSQ) [8] before and after each condition to measure the degree of motion sickness. The score after the trial was subtracted from the score before the trial, and the difference was used for analysis. Six naive participants, 20–24 years of age, participated in this experiment. Two trials, one trial for each condition, were carried out for each participant.

5.2 Results and Discussion

Figure 8 shows the average user feedback scores. The error bars show the standard error. Table 1 shows the result of a Wilcoxon signed-rank test. We found that traction trials were associated with significantly improved Acceleration (z=-2.23, p=0.026) and Enjoyment (z=-2.12, p=0.034) scores. Although we did not find significant differences for the other questions, we observed a consistent trend towards higher scores for trials with traction.

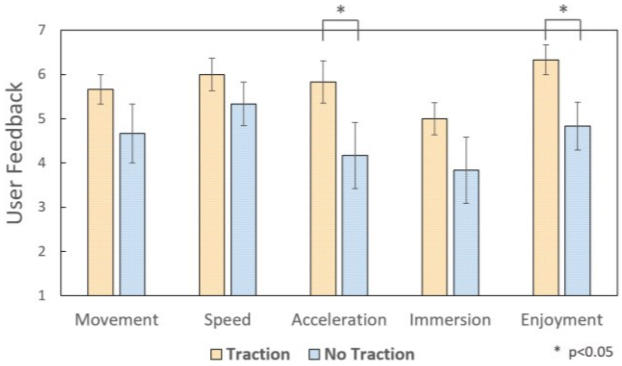

Figure 8. Average user feedback scores

Table 1. Results of Wilcoxon signed-rank test

	Traction		No Traction			
	M	SD	M	SD	z	p
Movement	5.67	0.33	4.67	0.67	-1.89	0.059
Speed	6.00	0.37	5.33	0.49	-0.96	0.34
Acceleration	5.83	0.48	4.17	0.75	-2.23	0.026
Immersion	5.00	0.37	3.83	0.75	-1.63	0.10
Enjoyment	6.33	0.33	4.83	0.54	-2.12	0.034

Figure 9 shows the average SSQ scores. The error bars show the standard error. Positive scores indicate an increase in motion sickness after a trial. A Wilcoxon signed-rank test revealed no significant differences between the two conditions.

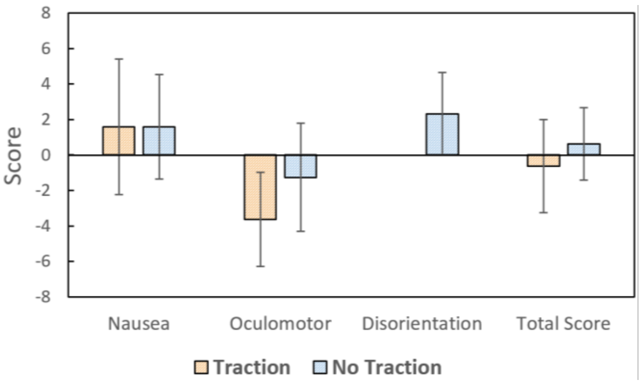

Figure 9. SSQ scores

We found that the clothes-pulling system improved the enjoyment of content score. Additionally, the feeling of acceleration was improved although the traction force was presented in accordance with velocity. However, most participants commented that the traction force was unnatural because it was not presented in accordance with acceleration. Indeed, this might explain the low immersion score. This was not consistent with the result from Experiment 1, in which users matched the traction force with velocity, not acceleration. One reason for this inconsistency might be that in Experiment 1, although the visual stimulus was sinusoidal (with positive and negative values), the force was presented only in the pulling direction. We intend to clarify this in future work by presenting forces in both directions.

The SSQ indicated a tendency towards decreased motion sickness with our traction system.

6. CONCLUSION

In this study, we tested a method for easily enhancing motion sensation via pulling on clothing. Experiment 1 indicated that the traction force should be presented in accordance with velocity. Experiment 2 revealed that enjoyment of content and the feeling of acceleration were improved by our system, but comments from the users implied that the traction force should be presented in accordance with acceleration. As this inconsistency is likely owing to a limitation of our system, we plan to develop a system that can present traction force in both forward and backward directions.

In our study, users wore hooded sweatshirts to facilitate the attachment of the clips to clothing. In the future, we plan to consider systems using seatbelts or harnesses. Additionally, attaching the system to a chair limits the chair in terms of size and shape. We plan to address this issue in future work.

7. ACKNOWLEDGMENTS

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