2017 IEEE World Haptics Conference (WHC)
Fürstenfeldbruck (Munich), Germany
6–9 June 2017

Pseudo Force Presentation to Multiple Fingers by Asymmetric Rotational Vibration Using a Motor: Consideration in Grasping Posture

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Abstract— **It is known that a pseudo force sensation of pulling in one direction is generated by presenting an asymmetrical vibration stimulus with different accelerations in a round trip. The present study employed a similar phenomenon using the asymmetric rotational vibration of a direct-current motor to present the pseudo force sensation to multiple fingertips. We investigated the frequency characteristics of this phenomenon for two fingers (i.e., the thumb and index finger) in a grasping posture, showing that vibration at a frequency around 30 Hz is optimal. We experimentally found that the equivalent physical force that this illusion generates is 10 to 30 grams, with large variance among participants in the study.**

I. INTRODUCTION

The haptic sensation felt when a person touches an object is a clue to the hardness, size and texture of the object. Diverse attempts have been made to reproduce this haptic sensation in a virtual reality (VR) environment. A method of physically driving a user's fingers or gripping objects when a user touches a virtual object to generate a haptic sensation to the fingers using exoskeleton-type [1] or gripping-type [2][3][4] devices has been researched and developed mainly by extending the technology of robotics; However, the method faces a problem in that the devices are large and complicated.

The vibration presented by a glove-type [5][6][7][8] device in which a transducer is arranged over the pad of the fingertip and entire palm is designed to be wearable by presenting only vibration. However, it takes a long time for the user to recognize the shape of the contact object because, for example, there is no force cue. Many methods of presenting a pressure sensation as a force cue have been proposed [9][10][11][12]. These methods use multiple motors, or a mechanism requiring a complicated mechanism such as a belt-and-link mechanism.

The presentation of a force sensation normally requires a device to be grounded and a reaction force to be applied to the human body. However, on the basis of human perceptual characteristics, a sense of being pulled in one direction is perceived when a reciprocating asymmetric vibration with different accelerations is presented, and it is possible to reproduce a pseudo force sensation [13][14][15][16][17]. Although this is a powerful means of presenting a haptic cue with a compact vibration device, the phenomenon has been observed only in the state that a person "grips" the transducer, and there has been no attempt to present the haptic cue to the fingertips in developing a VR glove.

Yem et al., meanwhile, found that a pseudo force sensation is generated by presenting asymmetric rotation with different accelerations in a round trip when a rotary direct-current (DC) motor is mounted on a fingertip [18]. This phenomenon is thought to be similar to the presentation of the artificial force sensation by conventional asymmetric vibration, but it can be felt even through the finger even without gripping the transducer. It is therefore considered to be useful in the development of a VR glove.

The present paper determines the appropriate motor vibration of two fingers for generating the pseudo force sensation phenomenon through the asymmetric rotation of a DC motor assuming the situation of grasping an object in an actual VR environment.

The study obtains the frequency of a sawtooth wave that generates a stable pseudo force sensation and measures the magnitude of the pseudo force sensation.

II. DEVICE OUTLINE

The device proposed for presenting a pseudo force is shown in Fig. 1.

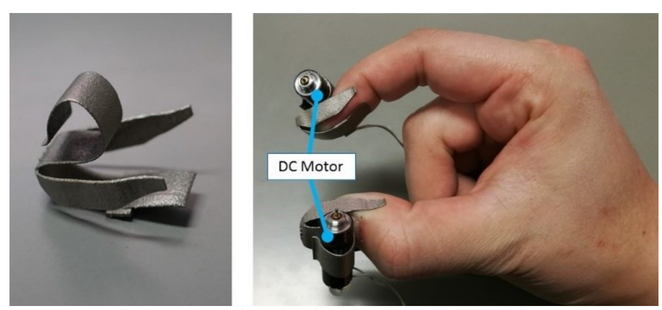

Fig. 1 Proposed device for presenting a pseudo force

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978-1-5090-1425-5/17/$31.00 ©2017 IEEE

The device comprises a DC motor (Maxon, 118396), a motor fixing sack (fingertip glove), an amplifier (Muse, M50), and a personal computer. The sack for fixing the DC motor to the fingertip is made from stainless steel metal and output by a three-dimensional printer and can be mounted such that the motor shaft rotates in the pitch direction with respect to the fingertip. In the present study, the pseudo force sensation presented to the user was in the direction of the pitch axis, and the finger felt a force in the direction from the finger pad to the fingernail (Fig. 2).

A pseudo force was sensed when a sawtooth wave or inverse sawtooth wave was input to the DC motor and the tip of the motor shaft was oriented orthogonal to the fingertip in a preliminary experiment (Fig. 3).

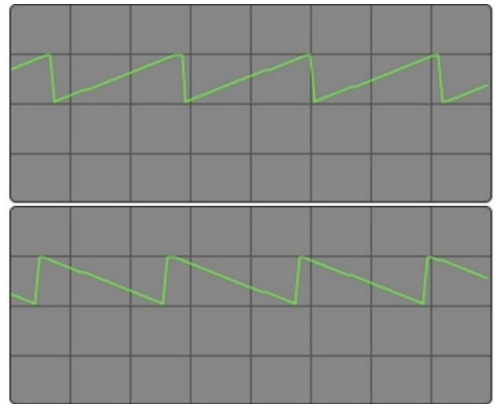
Fig. 3 Sawtooth wave (top) and inverse sawtooth wave (bottom)

III. Experiment 1

We conducted an experiment to determine the appropriate frequency of the stimulus presented using a DC motor when generating a simulated force. We presented a stimulus simultaneously to the thumb and index finger to generate pseudo forces with various combinations of direction, and recorded the impressions of participants in the experiment.

A. Experiment conditions

The experiment was conducted for eight participants (eight men, 22 to 28 years old, all right-handed) in a laboratory setting. As an asymmetric vibration stimulus with different round-trip accelerations and different accelerations, a sawtooth wave was generated using waveform generation software (Max/MSP). The frequency of the vibration stimulus was set at 10, 20, 30, 40, 50, 60, 70, and 80 Hz, and the applied voltage of the vibration stimulus was set at 6 and 12 V. In presenting independent vibration stimuli to the two fingers, there were four combinations of directions of the pseudo force sensation (Fig. 4). The pseudo force sensation was felt inward of the index finger and inward of thumb in condition 1, inward of the thumb and outward of the index finger in condition 2, inward of the index finger and outward of the thumb condition 3, and outward of the index finger and outward of the thumb in condition 4.

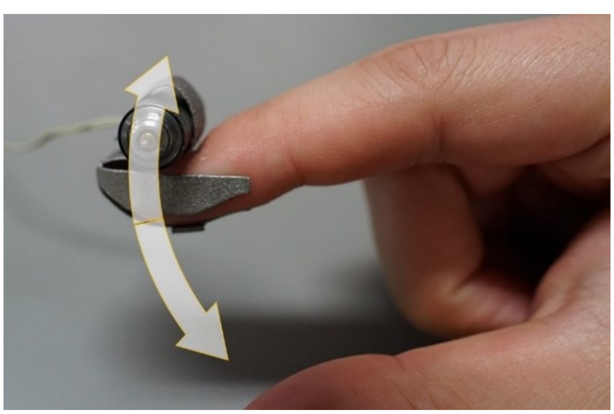
Fig. 2 Orientation of the pseudo force presented to the finger

B. Experimental procedure

The experimental scene is shown in Fig. 5. Participants attached devices to the thumb and index finger of the right hand and used noise-canceling headphones to suppress noise from the DC motor and external noise. Each participant was able to start the stimulus presentation by keyboard operation and each stimulus was presented for up to 10 seconds or until the participant answered. Participants reported which of the combinations of directions of pseudo force they perceived (as shown in Fig. 4) or that they did not perceive a force sensation.

128 trial measurements (i.e., four pseudo force sensation conditions × eight frequency conditions × two voltage values × 2 times) were performed in random order twice for each participant.

C. Experimental Results and Discussion

Fig. 6 summarizes the correct answer rates for the combination of perceived pseudo force sensations at each frequency for all participants. The horizontal axis represents the frequency while the vertical axis gives the correct-answer rate.

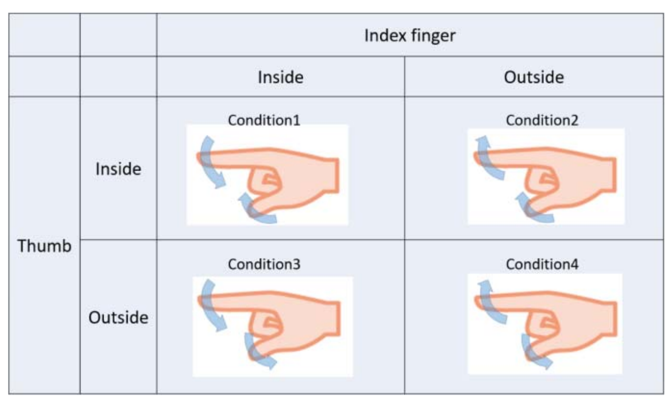

Fig. 4 Combination of force sensations for the thumb and index finger

Fig. 5 Scene of experiment 1

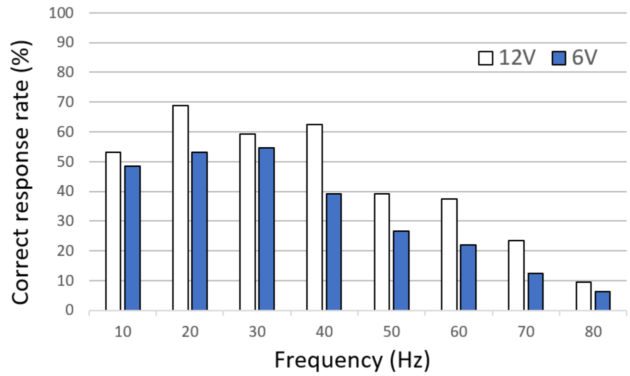

Fig. 6 Correct-response rate at each frequency

Fig. 6 shows the tendency that a relatively high correct answer rate was obtained at frequencies below 30 Hz. Moreover, when presenting the vibration stimulus at 40 Hz, the correct answer rate depended on the intensity of the presentation stimulus. In addition, almost all participants reported that they felt a pseudo force sensation more strongly when a low-frequency vibration stimulus was presented.

Table 1 gives the ratios of participant answers for the stimulus intensity of 12 V at frequencies below 50 Hz.

Items in orange cells in Table 1 indicate the proportions of trials for which the presentation stimulus and the subject's response matched. The match rate was highest under condition 1 and lowest under condition 4. This is interpreted as that the stimulus was felt more clearly on the side that bent the finger and less clearly on the side that extended the finger. One reason for this result is that this time the participants were taking a posture of grasping the thumb and index finger in parallel rather than a completely relaxed posture, which makes the stretching direction of the finger more active, thereby increasing the sensitivity in the extending direction. In addition, external forces that extend fingers are experienced more often on a daily basis than external forces that bend fingers, and there is the possibility that an external force that bends the finger is perceived vividly as an unusual experience.

Meanwhile, response rates were low for instances that the response was the exact opposite of the correct answer (e.g. condition 4 versus condition 1 and condition 3 versus condition 2), and the participant has at least one finger a pseudo force sensation in the expected direction.

IV. Experiment 2

In the second experiment, the magnitude of the pseudo force sensation actually felt by the user was quantified when the pseudo force sensation was generated using a DC motor. The pseudo force sensation generated by a sawtooth wave was used as the reference stimulus, and the magnitude of the pseudo force sensation in the backward direction of the finger for a gripping operation using two fingers (i.e., the thumb and index finger) was measured using a weight.

A. Experiment setup

The fingertip glove used in Experiment 1 was used to fix the transducer to the fingertip. When presenting a weight as a comparative stimulus, a load was applied to the finger pad of each of the two fingers using a pulley and. The experimental apparatus is shown in Fig. 7.

B. Experiment conditions

Experiments were conducted for eight participants (six men, two women, 21 to 28 years old, all right-handed) in a laboratory setting. The sawtooth waveform having a frequency of 30 Hz was used as the reference stimulus as it gave the most stable results among waveforms used in Experiment 1, and the applied voltage of the vibration stimulus was 12 V. In this experiment, we presented a pseudo force sensation to both fingers in the dorsal direction, and the participant reported whether the strength of the pseudo force sensation perceived by the fingertip was stronger or weaker than the force of the weight. The experimental scene is shown in Fig. 8.

Table 1 Response rate (%) at an applied voltage of 12 V below a frequency of 50 Hz

		Subject answer				
		1	2	3	4	0
Correct answer	1	71.9	7.8	6.3	3.1	10.9
	2	17.2	62.5	0	6.3	14.1
	3	17.2	3.1	59.4	6.3	14.1
	4	7.8	12.5	26.6	42.2	10.9

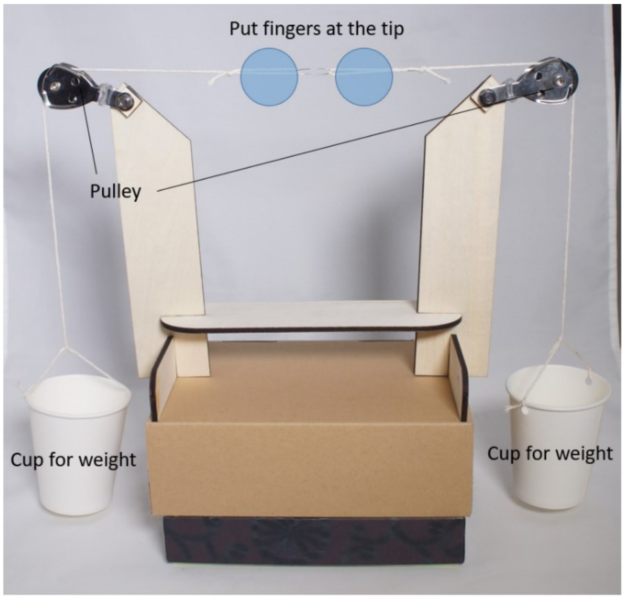

Fig. 7 Experimental apparatus

C. Experiment procedure

There were three procedures per trial in the experiment.

1. The participant wore a fingertip glove and learned the pseudo force sensation as a reference stimulus.
2. The participant removed the fingertip glove, hooked the weight onto their fingertip and compared the force with the pseudo force sensation.
3. The participant stated which stimuli felt stronger

The weight at the start of the experiment had a mass of 32 grams as determined in a preliminary experiment, and the subsequent weight was decided according to the parameter estimation by sequential testing (PEST) method using the responses of the participant [19]. The PEST method determined the stimulation intensity in the next trial as follows.

1. The stimulus intensity in the first step can be determined arbitrarily by the experimenter.
2. The step size is halved each time the direction of change of the stimulus intensity reverses.
3. If the direction does not reverse, the step size is the same as before.
4. When moving in the same direction for three or more consecutive steps, the step size is doubled but the upper limit is set so that the step size does not become too large.
5. If moving in the same direction in two consecutive steps, the step size is doubled or maintained according to the situation. If the step size immediately before the reversal of the most recent direction of change is doubled, the step size is doubled at this time. If not, the step size is maintained.
6. The measurement is ended when the step size becomes smaller than a predetermined value. The stimulation intensity at that time is set as a threshold.

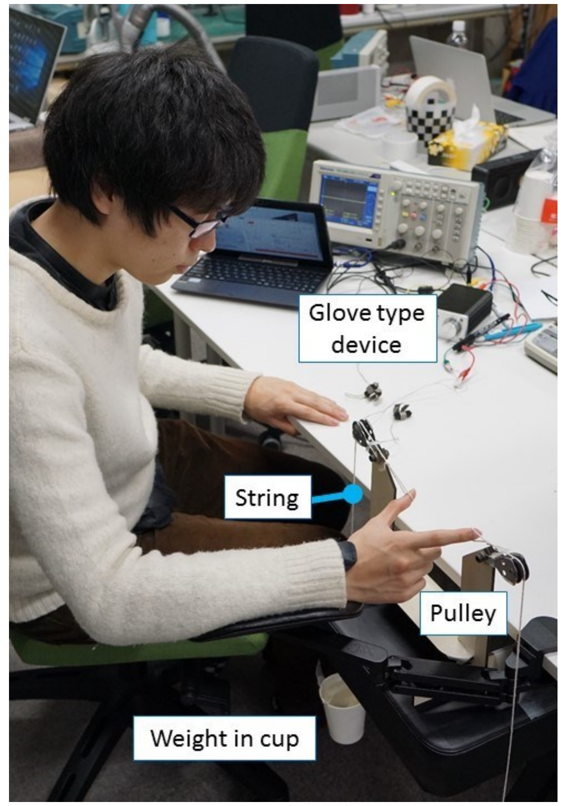

Fig. 8 Scene of experiment 2

In the present experiment, the minimum step size was set to 1 gram, and the stimulus intensity when the step size fell below this minimum step size was obtained. Five trials were conducted for each participant.

D. Experimental results

Fig. 9 summarizes the weights perceived by the pseudo force sensation for all participants in each trial. The horizontal axis represents the trial number and the vertical axis represents the magnitude of the pseudo force sensed by the participant. Fig. 9 shows that all participants perceived the strength of the pseudo force sensation to be about 10 to 30 grams. Regarding changes according to the number of experiments, there was no tendency common to all subjects. However, an internal report showed that the occurrence of the pseudo force sensation became ambiguous owing to vibration as the experiment trial progressed. It is thus believed that the present apparatus should be used to present the pseudo force sensation only over a short time, and it is considered that the user senses the pseudo force sensation less well when the apparatus is used for a long time.

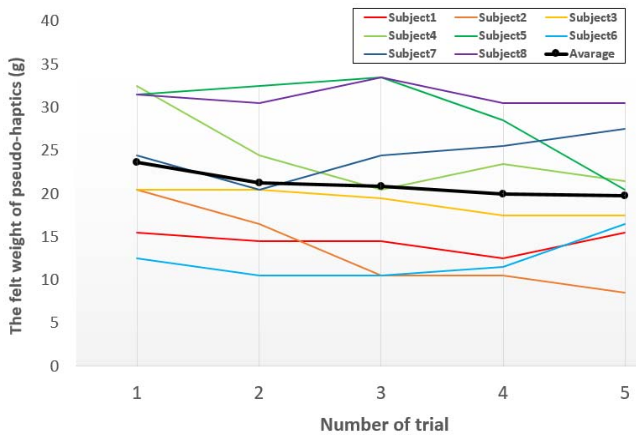

Fig. 9 Results of Experiment 2

V. Conclusion

We performed a preliminary study of a master hand that presents a pseudo-force sensation to multiple fingers employing the pseudo-haptic phenomenon resulting from asymmetric rotation with different accelerations in a round trip using a fingertip device powered by a DC motor. Combined conditions of finger pad–fingernail direction against four pseudo force sensations were prepared for the thumb and index finger, and the frequency of motor vibration suitable for the generation of the pseudo force sensation was determined. Experimental results showed that, especially at a frequency of 40 Hz or lower, the occurrence of the pseudo force sensation in at least one finger in the expected direction was high. On the basis of this result, we conducted an experiment to quantify the strength of the pseudo force sensation generated by a sawtooth wave with an applied voltage of 12 V and frequency of 30 Hz using a weight. When the user performed a grasping operation with their thumb and index finger, they felt a pseudo force sensation of approximately 10 to 30 grams.

In future work, we will examine the presentation of the pseudo force sensation for the grasping posture with five fingers, using an optimum waveform and optimum motor structure.

Acknowledgment

This research was conducted as part of the JST–ACCEL Embodied Media Project.

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