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Impact of Pulse Width and Pulse Oscillation Interval on Perception of Pseudo-Attraction Force

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***Abstract*—This paper discusses the effect of acceleration profiles on the kinesthetic illusion of being pulled (pseudo-attraction force perception). We have found that when a hand-held object oscillates in the hands, if the acceleration pattern is lopsided, one feels a pulling force sensation, although the object does move in two opposite directions. Our previous findings indicate that the pulse frequency of a lopsided oscillation determines the effective generation of the pseudo-attraction force. The object of this study is to clarify the effect of pulse width and pulse interval on force perception at the pulse frequency. The experimental results suggest that (i) there were no significant difference between pulse widths as regards perceiving a pseudo-attraction force, and (ii) there was a depressive interaction between pulse width and pulse interval with respect to force perception.**

***Index Terms*—Haptics, Perception, Pulse width, Pulse interval**

I. Introduction

Many force feedback devices have been developed in the last twenty years. However, most of them use either a mechanical linkage to establish a fulcrum relative to the ground [1], [2], or huge air compressors [3], [4]. Physical constraints mean that none of these devices can be used freely outside the laboratory. Although some mobile "torque" displays have been proposed [5], [6], they can produce neither a constant force nor a translational force, without also producing a reaction force; they can generate only a brief rotational force since they use a change in angular momentum.

We have proposed a new force perception method that can generate a translational force sensation with a long duration, which uses an asymmetric oscillation, where brief intense pulses of acceleration alternate with longer periods of low-amplitude recovery [7]. Although the net acceleration is zero, humans perceive a force sensation in the direction of the pulses. This is attributed to the nonlinear relationship between perceived acceleration and physical acceleration. We built a handheld prototype to generate periodic motion with asymmetric acceleration based on a method where asymmetric oscillation is generated by a slider-crank mechanism [8] or by a spring-cam mechanism [9]. Our previous findings indicate that the pulse frequency determines the effective generation of the kinesthetic illusion of being pulled [10], [11].

However, we have not clarified the effect of pulse width or pulse interval on force perception at the pulse frequency. To design a more appropriate acceleration profile, we conducted psychophysical experiments using an apparatus for generating an asymmetric oscillation based on a multicylinder mechanism, called NOBUNAGA (Fig. 1) [12], which can control pulse width, pulse interval, and pulse repetition cycle (i.e., frequency). This paper presents experimental results and discussion with a view to achieving the optimum design for the acceleration profile.

II. Experiment 1: Pulse Width

We have already showed that frequency of acceleration plays an important role for perceiving a pseudo-attraction force. In Experiment 1, we examined the effect of pulse width under the same frequency. We determined the percentage-error scores (i.e., how often the perceived force direction did not match the crank-to-slider direction) using two stimuli with different acceleration profiles.

A. Method

1) Participants: Twelve normal healthy adults (six men and six women) aged between 21 and 38 years (average 28.4) participated in Experiment 1. They had no known abnormalities as regards their tactile or kinesthetic sensory systems. They all stated that they were right-handed. None were involved in the research project or had experienced the pseudo-attraction force. All experiments performed during this research were approved by the local ethics committee.

2) Apparatus: The experimental system consisted of the NOBUNAGA, a computer equipped with an I/O board, and a power-supply and motor amplifier circuit. Unlike the previously used single slider-crank mechanism, NOBUNAGA can create a similar asymmetric oscillation but with a different pulse width or a different pulse interval. The rotation of the motor in NOBUNAGA (DC 6.0 V, 2232R006S; Faulhaber) was controlled at a constant speed by using a motor amplifier with an electronic governor function. A gear in the motor engages with a spur gear (reduction ratio: 10.5). With the spur gears, a crank in each module is rotated with a different phase. NOBUNAGA was 55 mm $\times$ 216 mm $\times$ 87 mm in size and weighed approximately 750 g.

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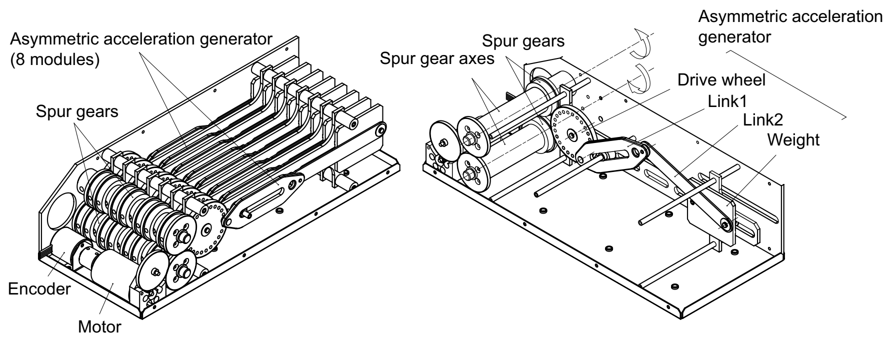


Fig. 1. Multicylinder mechanism for generating sequential pulses [12]. Each component module has a mechanism for generating an asymmetric acceleration based on the swinging slider-crank mechanism reported in [7].

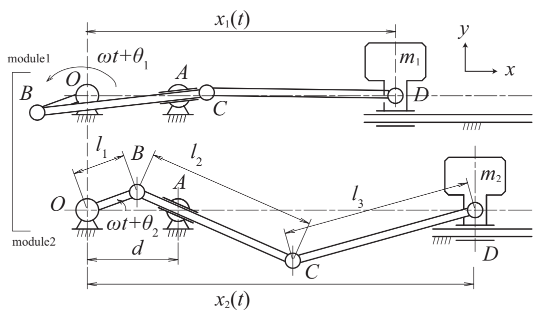


Fig. 2. Mechanism for changing the pulse width, pulse interval, and pulse repetition. The cranks in the modules were engaged with spur gears so that they rotated at the same velocity but in different phases.

3) Stimuli: The asymmetric oscillation (F) generated by the NOBUNAGA is

$$F(t) = \sum_{i=1}^{n} m_i \frac{d^2 x_i(t)}{dt^2} \tag{1}$$

where m_i is the weight in module i, n is the number of modules, and $\ddot{x}_i$ is the acceleration generated by module i. The acceleration $\ddot{x}_i$ is given by the second derivative with respect to time of the motion of the weight x_i. The equation for the motion of the weight in module i is

$$x_i(t) = l_1 \cos(\omega t + \theta_i) + \mu_i(d - l_1 \cos(\omega t + \theta_i)) + \sqrt{{l_3}^2 - \{l_1(\mu_i - 1)\sin(\omega t + \theta_i)\}^2} \tag{2}$$

where

$$\mu_i = \frac{l_2}{\sqrt{{l_1}^2 + d^2 - 2 l_1 d \cos(\omega t + \theta_i)}}, \tag{3}$$

and $x_i(t)$ = OD, d = OA, l_1 = OB, l_2 = BC, l_3 = CD, and ωt = AOB in Fig. 2. ω is the constant angular velocity, and t is time. θ_i is the initial phase difference of module i. In the device, d = 28 mm, l_1 = 15 mm, l_2 = 60 mm, and l_3 = 70 mm.

Two stimuli were used in Experiment 1 (Fig. 3). One has a sharper pulse width, n=1, $\omega/2\pi$ = 10, and m_1=20 g. The other has a duller pulse width, n=2, θ_2=θ_1+π, $\omega/2\pi$ = 5, and m_1= m_2=80 g. The amplitudes of both stimuli were adjusted to the same value by changing m_i. Therefore both had the same amplitude and the same asymmetric oscillation frequency (10 pulses per second), but they had different pulse widths. 10 pulses per second was selected based on our previous finding [11] that this frequency clearly generates the pseudo-attraction force.

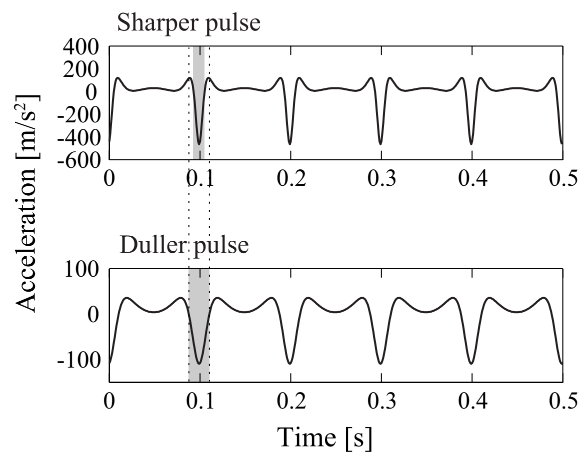


Fig. 3. Stimuli in Experiment 1. The sharper pulse (one module driven at 10 Hz) and duller pulse (two modules driven at 5 Hz with π different phase).

4) Procedure: Seated subjects held the force display with both hands as shown in Fig. 4 without any explanation about the mechanism or effect. The NOBUNAGA was handed to the subjects by an experimenter at each trial. The subjects were instructed not to squeeze the display, but to grasp it with just enough strength to keep it from slipping from their hands. Subjects were also instructed to keep it as horizontal as possible. Each subject performed 2 stimuli (sharper and duller pulses) $\times$ 100 trials (50 forward and 50 backward), for a total of 200 trials. The order in which the directions and frequencies were presented was randomized within each block of 50 trials. The subjects experienced the stimuli for two seconds per trial. The subjects pressed a foot pedal to indicate whether the perceived force direction was forwards

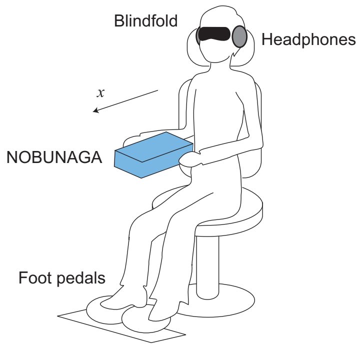


Fig. 4. View of experiment.

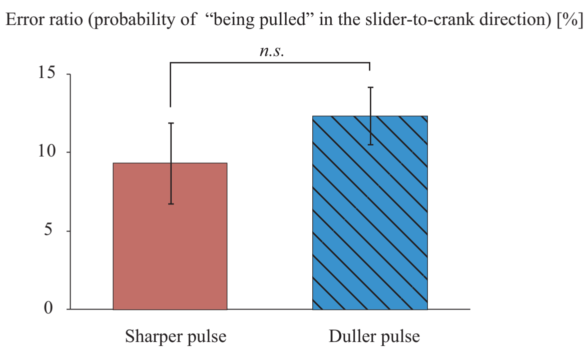


Fig. 5. Average percentage error scores over twelve subjects (100 trials per subject). Error bars show ± 1SE (standard error). No significant difference was seen.

or backwards in relation to their bodies. There was at least a 10-min break between each block of 50 trials to eliminate the effects of muscle strain and sensory adaptation. Correct-answer feedback was not provided during the experiment. To mask visual and auditory cues, the subjects were blindfolded and wore active noise-canceling headphones throughout the experiment.

B. Results

The proportion (or probability) of "being pulled in the slider-to-crank direction" (i.e., number of errors, incorrect answers) is shown in Fig. 5. The fact that the proportion is close to zero means that the pseudo-attraction force is well induced. None of the subjects' percentage error scores for either stimulus exceeded 25 %, which is the threshold for the binary judgment, or were less than 15 %, which indicates that both stimuli provide a directed force sensation (pseudo-attraction force sensation).

The average score with the sharper pulse was higher than that with the duller one, but no significant difference was seen ($t(11)=1.60$, $p=.14$; two-tailed pair-wise t-test).

III. Experiment 2: Pulse Interval

We determined the percentage-error scores using eight stimuli with different acceleration profiles.

A. Method

1) Participants and procedure: Eight of the subjects from Experiment 1 (average age 30.6 years) participated in Experiment 2. The procedure was the same as that of Experiment 1. Each subject performed 8 stimuli × 100 trials, for a total of 800 trials.

2) Stimuli: Eight different stimuli, divided into two groups, were used in this experiment (Fig. 6). One group had a sharper pulse, m_1=20 g, and $\omega/2\pi = 10$. The other group had a duller pulse width, m_1= m_2=80 g, and $\omega/2\pi = 5$. The amplitudes of all the stimuli were adjusted to the same value by m_i. Therefore the stimuli in each group had the same asymmetric oscillation amplitude and pulse width, but they had different pulse intervals.

The stimuli were generated by the NOBUNAGA with the following parameters; (1) $\theta_2=\theta_1$, (2) $\theta_2=\theta_1+\pi/4$, (3) $\theta_2=\theta_1+\pi/2$, (4) $\theta_2=\theta_1+\pi$. With the duller pulse, (1) generates an acceleration pattern with a pulse interval of 200 ms, (2) generated an acceleration pattern with pulse intervals of 25 and 175 ms, (3) generated an acceleration pattern with pulse intervals of 50 and 150 ms, and (4) generated an acceleration pattern with a pulse interval of 100 ms. With the sharper pulse, (1) generates an acceleration pattern with pulse interval of 100 ms, (2) generated an acceleration pattern with pulse intervals of 12.5 and 87.5 ms, (3) generated an acceleration pattern with pulse intervals of 25 and 75 ms, and (4) generated an acceleration pattern with a pulse interval of 50 ms.

B. Results

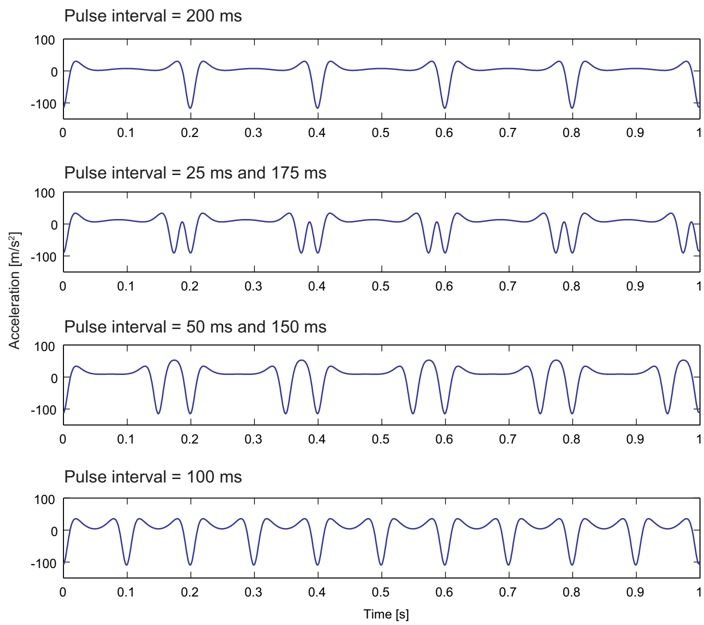
Figure 7 shows the results of Experiment 2. The acceleration pattern with the duller pulse and a 200-ms pulse interval provided the best performance of all the stimuli. A repeated measures analysis of variance (ANOVA) of the percentage error ratio was performed for each group.

With the duller pulse, Mauchly's test of sphericity indicated that the assumption of sphericity had been violated ($\chi^2(5) = 20.68$, $p<.01$). Therefore, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.38$). The results revealed a significant effect for the pulse interval with the duller pulse ($F(1.15,\ 8.05)=8.18$, $p<.05$), which indicates that the pulse interval is influential. Post hoc comparisons were made using the Tukey honestly significant difference (HSD) test. The differences between the duller pulse stimuli with pulse intervals of 25–175 ms and that of 100 ms, and between that of 25–175 ms and that of 50–150 ms were significant ($p<.01$).

With the sharper pulse, the pulse interval had no significant effect ($F(3,\ 21)=1.84$, $p=.17$, n.s.).

IV. General Discussion

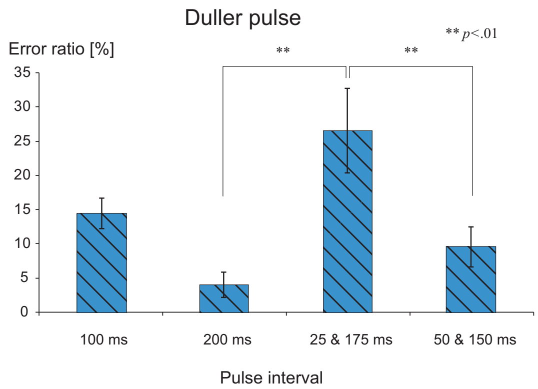
The results show that larger pulse widths seem to degrade the participants' performance. However, no significant differences were observed in the results of Experiment 1. We speculate that the acceleration profile with larger pulse widths than that previously reported can be used to generate a pseudo-attraction force. Larger pulse widths might produce a smoother



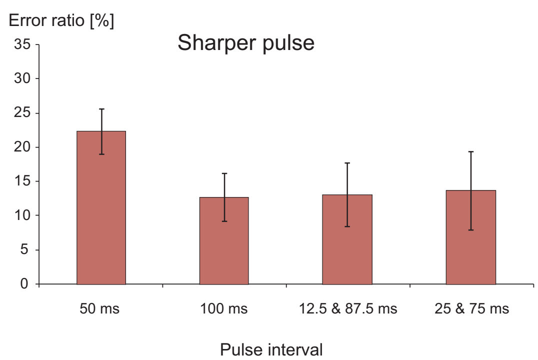
(a) Duller pulse

(b) Sharperer pulse

Fig. 6. Stimuli with different pulse intervals used in Experiment 2.



(a) Duller pulse



(b) Sharper pulse

Fig. 7. Error ratio results for several different pulse intervals. Error bars show ± 1SE.

pulling force sensation, since spiky stimuli of around 10 Hz generally tend to induce a discrete rather than a smooth pulling sensation.

We observed a depressive interaction between pulse width and pulse interval as regards force perception for duller pulse stimuli with pulse interval of 25–175 ms. The interaction was only seen with duller pulse stimuli. 25 ms is not magic number for perception (because the same interval with sharper stimuli of 25–75 ms did not produce the same performance) and the ratio of 1:7 (i.e., 25 ms : 175 ms) is also not a magic ratio [because the same ratio (i.e., 12.5 : 87.5 ms) did not produce the same performance]. One possible explanation for this is a subtle amplitude difference: The acceleration amplitude for a 25–175 ms pulse interval was slightly smaller than for the others, because of the summation of pulses. This remains controversial, so we will investigate it while controlling other possible factors.

The approach used in this article is involved coupling several copies of an identical slider-crank mechanism. This appears to be unsuitable for practical use in terms of size, weight, and mechanical complexity. However, the reason for our mechanical approach is to control the waveform with a sufficiently large intensity to generate a clear force sensation. It is true that there are many other electromechanical devices that can create controllable waveforms by varying the excitation signal rather than changing the mechanical structure, but it is impossible to produce a force sensation, because the waveform amplitude is too small to induce a pseudo-attraction force in a low frequency range with the size of hand-held devices. Future work will involve generating an asymmetric oscillation with a large force without using a mechanical structure.

V. Conclusion

We conducted psychophysical experiments using a NOBUNAGA to examine the effects of pulse width and pulse interval with respect to force perception. The experimental results suggest that an increase in the pulse width of an asymmetric oscillation slightly degrades the perception of the pseudo-attraction force, but the degradation is not statistically significant. This suggested that it is possible to generate a smoother pulling force sensation. We will continue to investigate the effect of the pulse width and the asymmetric oscillation interval with a view to designing an effective acceleration profile for perception.

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References

[1] T. H. Massie and J. K. Salisbury, "The phantom haptic interface: A device for probing virtual objects," in *Proc. the ASME Winter Annual Meeting, Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, vol. 55-1, Chicago, IL., 1994, pp. 295–300.

[2] M. Sato, "Spidar and virtual reality," in *Proc. the 5th Biannual World Automation Congress*, vol. 13, 2002, pp. 17–23.

[3] H. Gurocak, S. Jayaram, and J. U. Parrish, B., "Weight sensation in virtual environments using a haptic device with air jets," in *Journal of Computing and Information Science in Engineering*, vol. 3, no. 2. ASME, 2003, pp. 130–135.

[4] Y. Suzuki, M. Kobayashi, and S. Ishibashi, "Design of force feedback utilizing air pressure toward untethered human interface," in *Proc. CHI '02 Extended Abstracts on Human Factors in Computing Systems*. ACM Press, 2002, pp. 808–809.

[5] Y. Tanaka, S. Masataka, K. Yuka, Y. Fukui, J. Yamashita, and N. Nakamura, "Mobile torque display and haptic characteristics of human palm," in *Proc. the 2001 International Conference on Augmented Tele-existence*, 2001, pp. 115–120.

[6] H. Yano, M. Yoshie, and H. Iwata, "Development of a non-grounded haptic interface using the gyro effect," in *Proc. Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*. IEEE Computer Society, 2003, pp. 32–39.

[7] T. Amemiya, H. Ando, and T. Maeda, "Virtual force display: Direction guidance using asymmetric acceleration via periodic translational motion," in *Proc. World Haptics Conference*. IEEE Computer Society, 2005, pp. 619–622.

[8] T. Amemiya and T. Maeda, "Directional force sensation by asymmetric oscillation from a double-layer slider-crank mechanism," *Journal Computing Information Science in Engineering*, vol. 9, no. 1, 2009.

[9] T. Amemiya, H. Ando, and T. Maeda, "Hand-held force display with spring-cam mechanism for generating asymmetric acceleration," in *Proc. World Haptics Conference*. IEEE Computer Society, 2007, pp. 572–573.
[10] T. Amemiya and T. Maeda, "Asymmetric oscillation distorts the perceived heaviness of handheld objects," *IEEE Transactions on Haptics*, vol. 1, no. 1, pp. 9–18, 2008.
[11] T. Amemiya, H. Ando, and T. Maeda, "Lead-me interface for pulling sensation in hand-held devices," *ACM Transactions on Applied Perception*, vol. 5, no. 3, pp. 1–17, 2008.
[12] T. Amemiya and T. Maeda, "Nobunaga: Multicylinder-like pulse generator for kinesthetic illusion of being pulled smoothly," in *Proc. EuroHaptics Conference*, 2008, pp. 580–585.