Improvement of Sensory Stabilization and Repeatability of Vibration Interface for Distance Presentation

Yuki Sampei[1], Takayuki Tanaka[1], Yuki Mori[2], and Shun'ichi Kaneko[1]

[1] Hokkaido University, Kita 14 Nishi 9,Kita-ku, Sapporo, Hokkaido, 060-0814, Japan
sampei@ssc.ssi.ist.hokudai.ac.jp
[2] Riken, Nagoya, Japan

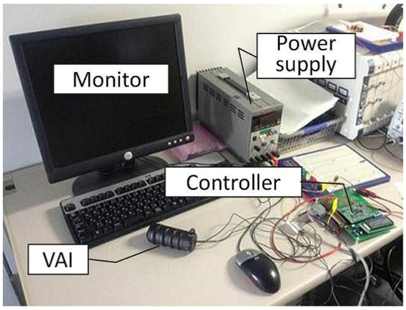
Abstract. We have developed a vibration alert interface (VAI) that provides information through various vibration patterns. In our previous studies, we designed the VAI and its vibration patterns to provide analog-like information to users such as distance to obstacles. Precise information recognition requires correct perception of vibration patterns. However, various disturbances can affect perception of vibrations, causing users to perceive similar vibrations as being different. We therefore proposed the *relative vibration sense presentation* method to avoid disruption of the vibration sense. In this paper, we experimentally show that this method improves the repeatability of vibration sensation. We also propose a vibration presentation model for drivers to correct perception gaps due to the application and surroundings of VAI. We evaluate the proposed model through experimentation.

1 Introduction

We developed the vibration alert interface (VAI) to provide information through varying vibration patterns. Vibration is an effective method for conveying information to individual users. In previous studies, we designed VAI and its vibration patterns to provide analog information such as distance to obstacles [1]. Conventional vibration devices convey information by turning vibrations on or off [2][3]. We found that a higher frequency vibration motor can convey greater vibration strength to users.

Precise information recognition requires correct perception of vibration patterns. However, various disturbances can affect perception of vibrations, causing users to perceive similar vibrations as being different [4][5]. One of the things which give information by vibration is a sound. A sound is defined as follows [6]. A phoneme is one element in the sound system of a language having a characteristic set of interrelations with each of the other elements in that system. The phonemes cannot be defined acoustically and they are a set of abstractions. It state that it isn't sound but a sound difference, i.e., contrast, which should be perceived in a sound system [7]. We therefore developed a new presentation method for vibration that avoids disruption of the vibration sense. The proposed *relative vibration*

D.D. Schmorrow and C.M. Fidopiastis (Eds.): AC/HCII 2013, LNAI 8027, pp. 734–743, 2013.



(a) Experimental setup and VAI.

(b) State of participant and VAI.

Fig. 1. The vibration alert interface (VAI)

sense presentation (RVSP) method alternately presents a presentation vibration frequency f_p and a constant base vibration frequency f_b.

In this paper, we experimentally show that RVSP improved repeatability of vibration sensations. Further, we propose a vibration presentation model for drivers to correct perception gaps due to the application and surroundings of VAI. We evaluate the proposed model through experimentation.

2 Vibration Alert Interface

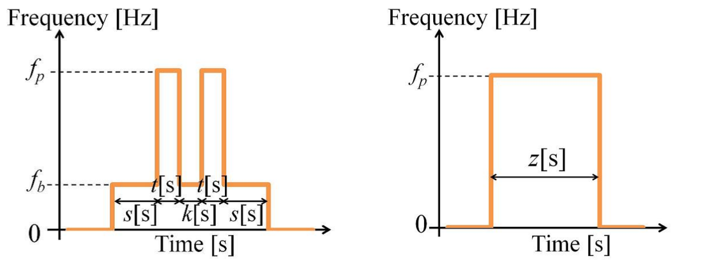
2.1 Experimental Systems and Conditions

Fig. 1(a) shows the structure of the VAI experimental device. The vibrator is a cylindrical plastic object containing a small vibrating motor. Participants held it, and vibration frequency was controlled through an H8 microcomputer and PC-based motor driver. The participants in the experiment were four healthy adult men and women age 21 to 22 (21.8 average). To ensure only tactual judgment, participants wore eye masks and listened to white noise via headphones (Fig. 1(b)).

According to Weber–Fechner's law, sensations are perceived in proportion to the logarithm of the stimulation [8][9]. The amplitude of VAI vibration used in this research is independent of the frequency, so we can define the quantity of user vibration perception as

$$E = k_f \log f + C, \tag{1}$$

where f is the vibration frequency, k_f is the gain, and C is a constant. Since the energy of vibration is proportional to the logarithm of the frequency, the magnitude of the energy is controllable by controlling the frequency.



(a) The relative vibration sense presentation (RVSP) method.

(b) The absolute vibration sense presentation (AVSP) method.

Fig. 2. Definitions of the presentation methods ($f_b > 0$)

2.2 Relative Vibration Sense Presentation Method

Factors related to changes in vibration perception for similar vibrational frequencies include the contact area and changes in the grip force. In this research we focus on the existence of C, the unknown constant in Eq. (1). In conventional presentation methods, since the presentation vibration f_p [Hz] is given after a state of no vibration (0 [Hz]), C varies with every presentation. We predict that the dampening of vibration sense is due to the instability of C.

We therefore propose the *relative vibration sense presentation* (RVSP) method to improve the repeatability of the vibration sense provided by the VAI. RVSP alternately presents a presentation vibration frequency f_p and a constant base vibration frequency f_b. It aims at reducing the influence of C in Eq. (1) by presenting ΔE, which is the difference between the quantity of sense by presentation vibration E_p and the quantity of sensation by base vibration E_b. k_f and C are assumed to be fixed by continuous oscillating presentation. This with Eq. (1) gives Eq. (2). We consider that users can perceive correct information from f_p in comparison with f_b by eliminating C, as in Eq. (2).

$$\Delta E = E_p - E_b = k_f(\log f_p - \log f_b) \tag{2}$$

We perform an experimental investigation to determine if RVSP improves reproducibility of vibration sense more than does the *absolute vibration sense presentation* (AVSP) method, which does not use a base vibration frequency. Fig. 2(a) shows the RVSP vibration pattern, and Fig. 2(b) shows the pattern for AVSP. In that figure, t is the presentation time of the presentation vibration in RVSP, s and k are the presentation times of the base vibration in RVSP, and z is the presentation time of the presentation vibration in AVSP. A cycle of a given vibration in RVSP is called a presentation vibration cycle.

Although $\log f$ would be infinitely large in Eq. (1) at times where $f = 0$ [Hz], there are dead zones in human perception of stimuli, and the threshold of the vibration frequency changes with the equipment used. We consider that there is no quantity of vibration sense in states where VAI vibrates at vibration frequencies less than f_0. Eq. (1) is therefore redefined as follows:

$$E = \begin{cases} 0 & \text{if} \quad f < f_0 \\ k_f \log f + C & \text{otherwise} \end{cases} \tag{3}$$

3 Verification of the Validity of RVSP

3.1 Comparison of RVSP and AVSP

We conducted experiments that compare RVSP with AVSP to verify the validity of RVSP. Since RVSP needs the existence of the base vibration, which has the vibration frequency more than fixed, we sets it to $f_b = 100$ [Hz] and advances verification.

The parameters for RVSP were set as $s = 2$, $t = 1$, and $k = 1$ (Fig. 2). This vibration pattern is called *rel* below. The parameter of AVSP were set as $z = 5$. This vibration pattern is called *abs* below. The presentation vibration frequencies were set to 100, 115, 130, 145, and 160 [Hz]. Participants reported perceived vibration strength v_s as an integral value.

Experimental procedures were as follows:

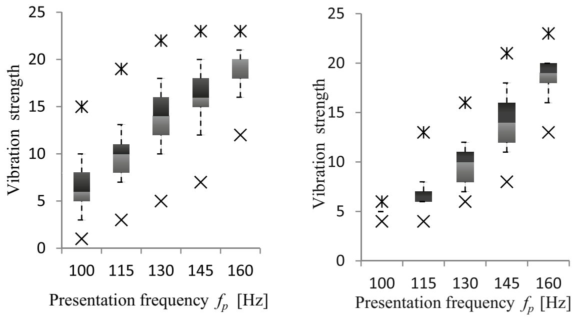
(1) Participants grasped the VAI vibrating at $f_p = 100$ [Hz], and were told to classify perception of this vibration as strength 5.
(2) Next, they were presented with a new vibration strength, $f_p = 160$ [Hz], which they were told to classify as vibration strength 20.
(3) Finally, participants were presented with vibration at a random frequency, and reported the perceived vibration strength.
(4) Steps (1)–(3) were repeated five times.

We repeated this process ten times per day for each participant, with short breaks between presentations. This was repeated over six days, resulting in 60 data points regarding vibration strength perception for various frequencies for each participant. The experiment that presents *rel* was carried out after completion of the experiment that presents *abs*.

Fig. 3 shows the results for all participants. As the box plots indicate, the standard deviation for *rel* was smaller than for *abs* at all frequencies (Table 1). Comparing results between participants, the same result was obtained in 17 out of 20 pairs of data groups (four participants, five frequencies each). This confirms that the variation in vibration strength was small under RVSP, and thus that RVSP with $f_b = 0$ is effective.

3.2 Presentation Vibration Cycle

We changed the presentation vibration cycle of RVSP, and carried out other experiments. The parameters of RVSP were set as $s = 1$, $t = 1$, $k = 1$, and



(a) *abs.* (b) *rel.*

Fig. 3. Comparing *rel* and *abs* in terms of repeatability

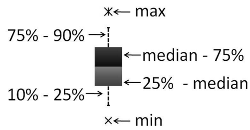


Fig. 4. How to read our box plot

Table 1. Comparing *rel* and *abs* in terms of standard deviation and improvement rate

Presentation vibration frequency [Hz]	Standard deviation *abs*	Standard deviation *rel*	Improvement rate[%] *abs rel*
100	2.56	0.14	94.3
115	2.99	1.12	62.4
130	3.13	1.94	37.9
145	2.82	2.55	9.70
160	2.08	1.72	17.6
Average	2.71	1.50	44.4

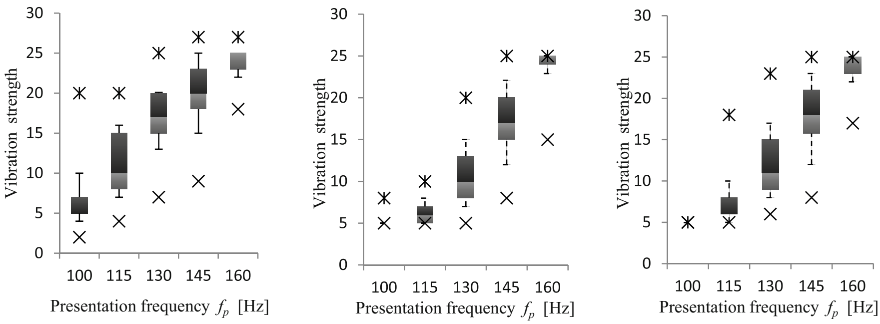
$s = 2$, $t = 2$, $k = 2$ (Fig. 2). These vibration patterns are respectively called *rel*-1 and *rel*-2 below. AVSP parameters were set as $z = 3$. This vibration pattern is called *abs*-3 below. The presentation vibration frequencies were set to the same five levels as in the previous section.

Experimental procedures were as follows:

(1) Participants grasped the VAI vibrating at $f_p = 100$ [Hz], and were told to classify perception of this vibration as strength 5.
(2) Next, they were presented with a new vibration strength, $f_p = 160$ [Hz], which they were told to classify as vibration strength 25.
(3) Finally, Participants were presented with vibration at a random frequency, and reported the perceived vibration strength.
(4) Steps (1)–(3) were repeated five times.

We repeated this process 15 times per day for each participant, with short breaks between presentations. This was repeated over 3 days, resulting in 45 data points regarding vibration strength perception for various frequencies for each participant. We carried out these experiments in the order *abs*-3, *rel*-1, then *rel*-2.

Fig. 5 shows the results for all participants. Standard deviations of *rel*-1 and *rel*-2 were smaller than that of *abs*-3 at frequencies 100 and 115 [Hz], but larger at frequencies 130, 145, and 160 [Hz] (Table 2). In between-participant comparisons, however, *rel*-1 was smaller than *abs*-3 in 17 of 20 pairs, and *rel*-2 obtained the same result in 18 of 20 pairs. We thus found that the variation in vibration strength was small under RVSP for each participant. The above analysis shows that in each participant *rel*-1 and *rel*-2 suppressed variation in the vibratory sense, as compared with *abs*-3.



(a) *abs*-3. (b) *rel*-1. (c) *rel*-2.

Fig. 5. Comparison of *rel*-1, *rel*-2, and *abs*-3 for differences in vibration perception

Table 2. Comparison of *rel*-1, *rel*-2, and *abs*-3 standard deviation and improvement rate

Presentation vibration frequency [Hz]	Standard deviation			Improvement rate[%]	
	abs	*rel*-1	*rel*-2	*abs*-3*rel*-1	*abs*-3*rel*-2
100	2.47	0.25	0.00	90.0	100
115	3.70	1.47	1.93	60.2	48.0
130	3.33	3.94	3.58	-4.91	-7.51
145	3.65	3.74	3.98	-2.51	-9.19
160	1.66	1.69	1.67	-1.80	-0.918
Average	2.95	2.13	2.23	28.2	26.1

4 Perceptual Model to Convert Vibration Stimulation to Distance Perception

4.1 Systems

We assume two hypotheses as in Fig. 6 concerning the mechanism by which humans recognize vibratory stimulation as distance perception.

(I) The relation H_1 between vibratory stimulation and vibration strength is independent of the VAI application.
(II) The relation H_2 between vibration strength and distance perception is dependent on the VAI application.

We examine the relations H_1 and H_2 during driving to develop VAI-C, which applies VAI to support drivers with information such as distance to obstacles. We then verify the above-mentioned hypotheses. The influence on these relations by driving speed is experimentally investigated with a driving simulator. Finally, we confirm that VAI-C presents stable distance perception, independent of driving speed. Fig. 7 shows the experimental setup.

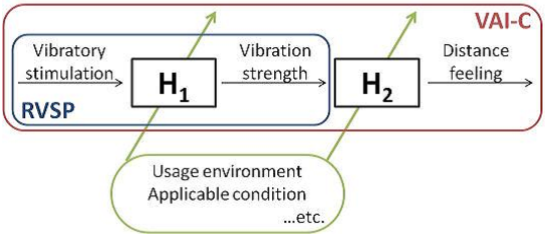


Fig. 6. Hypotheses regarding human perception

Fig. 7. Configuration of VAI-C and participant

4.2 VAI-C Systems

A driving simulation (FORUM8 Corp.) was displayed on three monitors. Participants were three healthy adult men aged 22 to 23 years (average 22.7 years). Participants held the VAI and listened to white noise via headphones, and the experiment was conducted in a darkened room, thus limiting sensory information other than screen information and VAI oscillations. Using the driving simulator software, we created a virtual straight road on flat ground, with trees on both sides at a fixed interval. Participants were exposed to AVSP with parameter $z = 3$ (Fig. 2). The presentation vibration frequencies varied over 15 settings, from 95 to 165 [kHz] in 5 [kHz] increments, and driving speeds were 30, 60, and 90 [km/h]. This resulted in 45 patterns of varying presentation frequency and driving speed.

4.3 Experimental Exploration of Relations

We performed two experiments to investigate relationships among vibration stimulation, vibration sense, and distance perception. In particular, we wanted to ascertain the following:

(A) Whether differences in driving speed affect vibratory perception.
(B) Whether differences in driving speed affect distance perception.

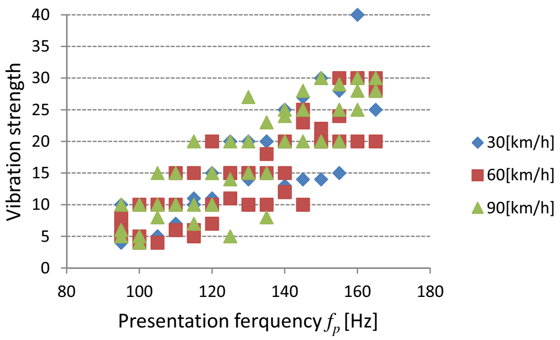
Experimental procedures were as follows:

(A) Driving speed and vibratory sense
  (1) Participants grasped the VAI vibrating at $f_p = 100$ [Hz], and were told to classify perception of this vibration as strength 5.
  (2) Next, they were presented with a new vibration strength, $f_p = 160$ [Hz], which they were told to classify as vibration strength 30.
  (3) Finally, participants were presented with one of the random frequency and speed patterns, and reported the vibration strength.
  (4) Steps (1)–(3) were repeated five times.

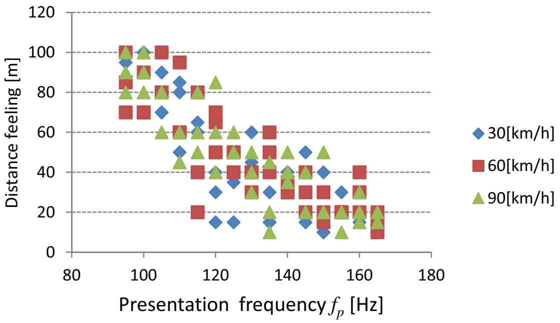
(B) Driving speed and distance perception
  (1) Participants grasped the VAI vibrating at $f_p = 100$ [Hz], and looked at monitors in which a vehicle was 100 [m] ahead. They were told to classify perception of this vibration as that felt for an object 100 [m] away.
  (2) Next, they were presented with a new vibration strength, $f_p = 160$ [Hz], and looked at monitors in which a vehicle was 10 [m] ahead. They were told to classify perception of this vibration as that felt for an object 10 [m] away.
  (3) Finally, participants were presented with one of the random frequency and speed patterns, and reported the distance perception.
  (4) Steps (1)–(3) were repeated five times.

The driving speed was 60 [km/h] in steps (1) and (2). We repeated this process 3 times per day for each participant, with short breaks between presentations. This was repeated over 3 days, resulting in 45 data points regarding vibration strength perception for each participant. Experiment (B) was carried out after completion of experiment (A).

Fig. 8 shows the results for all participants. Both vibration strength and distance perception form a numerical distribution without regard to driving speed, indicating no influence of driving speed on distance or vibration strength perception. This differs from our hypothesis. Our data are currently limited, however, so further investigation is required.



(a) Driving speed and vibration strength.



(b) Driving speed and distance perception.

Fig. 8. The relationship among driving speed, vibration strength, and distance perception

5 Conclusion

This paper showed the repeatability of vibration sensation improvement by the relative vibration sense presentation method. Furthermore, we developed a hypothesis about the relationship of human perception and verified it experimentally.

References

1. Mori, Y., Tanaka, T., Kaneko, S.: Design of Vibration Alert Interface based on Vibration Strength Considering Skin Deformation with Respect to Grip Force. Human Interface Society 12(2), 103–111
2. Yao, H.S., Grant, D., Cruz, M.: Perceived Vibration Strength in Mobile Devices: the Effect of Weight and Frequency. IEEE Transaction on Haptics (2009)

3. Morioka, M., Griffin, M.J.: Magnitude-dependence of equivalent comfort contours for foreandart, lateral and vertical hand-transmitted vibration. Journal of Sound and Vibration 295, 633–648 (2006)
4. Nishiyama, K., Watanabe, S.: Temporary Threshold Shift of Vibratory Sensation After Clasping a Vibrating Handle. International Archives of Occupational and Environmental Health 49, 21–33 (1981)
5. Maeda, S., Griffin, M.J.: Temporary threshold shifts in finger tip vibratory sensation from hand-transmitted vibration and repetitive shock. British Journal of Industrial Medicine 50, 360–367 (1993)
6. Gleason, H.A.: An introduction to descriptive linguistics. Rinehart & Winston, New York, Holt (1961)
7. Minematsu, N., Nishimura, T.: Relative Sense of Speech - A Study of Equality between Speech and Music-. Information Processing Society of Japan (IPSJ). SIG Notes 2005(127), 211–216 (2005)
8. Fechner, G., Adler, H., Howes, D., Boring, E.: Elements of Psychophysics. Rinehart and Winston, New York, Holt (1966)
9. Oyama, T., Imai, S., Wake, T.: New Edition - Handbook for Sense and Perception of Psychology. Seishinsyobo (1994) (in Japanese)