Design of Vibration Alert Interface Based on Tactile Adaptation Model to Vibration Stimulation

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Abstract. In this paper, we describe the influence of vibratory adaptation on vibration perception and its correction method. Vibration strength after change depends on the vibration frequency before change even if the vibration frequency itself does not change. We found that the higher the vibration frequency before change, the weaker the perceived vibration strength. To correct this perception gap, the frequency before change is fed back to the KI model that expresses the vibratory adaptation. We performed a simulation to show that output of the KI model is able to express changes in vibration caused by adaptation.

Keywords: Vibration, Adaptation, Sense of touch.

1 Introduction

Recent studies have focused on conveying information through the sense of touch, including vibrations, and tactile impressions. As an example, a system that conveys road-departure warnings and proximity warnings to drivers by steering wheel vibrations has already been put to practical use in cars.

Much information is displayed in a visual manner, but it is necessary to consider the user's line of sight and how disruptive it might be to, for example, driving car. In the case of information presented through audible sounds, the information is conveyed not only to the user, but also individuals located in the vicinity of the user, which might be undesirable for the given application. Information conveyed through vibrations does not have these drawbacks. Therefore, research has been conducted on a number of topics regarding the presentation of information through touch, such as [1][2][3].

In this paper, we present a vibration alert interface (VAI) that consists of multiple vibration frequencies. Conventional devices using vibration convey only one bit of information to indicate danger based on an on/off control of the vibration motor. The VAI aims to convey analog-like information by using changes in the vibration frequency; however, such changes in vibration are not always perceived due to human adaptation, which poses a problem for VAI applications. More specifically, even if the vibration frequency is the same, user perception changed based on vibratory adaptation.

In addition to this introductory section, this paper is organized as follows:

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Section 2 describes our experimental results regarding changes in vibration perception due to adaptation; Section 3 explains the KI model and our proposed correction method for the change in vibration perception induced by adaptation; in Section 4, we confirm through simulation that the KI model is able to express the vibratory adaptation and is effective in correcting the perception gap; and we conclude our paper and discuss future work in Section 5.

2 Change in Vibration Perception Induced by Adaptation

The VAI is a device that conveys information to users by using vibrations. Users recognize such information as proximity or danger from the VAI by perceiving the vibration strength, frequency, and pattern; however, a user's vibration perception changes due to disturbance [4][5][6]. Therefore, it is necessary to consider this disturbance in designing the VAI to keep the vibration perception of the user constant. For this, we conducted experiments to examine the change in vibration perception induced by vibratory adaptation in the form of disturbance.

2.1 Experimental Setup

For our experiments, we used magnitude estimation as an approach. Magnitude estimation is a scaling method used in psychophysics to evaluate a subject's perception of stimulus intensity. Our experimental method was as follows:

1. Subjects grasp the VAI vibrating at 110 Hz and are informed that the stimulus has a magnitude of 10.
2. The VAI is vibrated at frequencies 70, 90, 110, 130, or 150 Hz. The frequencies are randomly selected. Vibration at each of these frequencies lasts for 5 sec. These frequencies are labeled as frequency before change.
3. The frequency of VAI change. Subjects reported their perceived vibration strength relative to the standard strength of 10 after the change in frequency. These frequencies are labeled as frequency after change.

This experiment examined the change in vibration perception after the frequency change as a function of the vibration frequency before change. In this experiment, the vibration device shown in Fig. 1(a) was used as the VAI. The diameter and length of the vibration device are 4 cm and 10 cm, respectively; a vibration motor was mounted inside the device. The test involved 13 subjects, both males and females, with an average age of 24.5 years. Subjects wore eye masks and heard white noise with headphones during the experiment to ensure they were focused solely on their tactile senses.

2.2 Experimental Results

We examined the difference of vibration perception after change that is caused by the frequency before change by changing the frequency to each of the possible values noted above. The correlation coefficient between the frequency before change and the reported vibration perception after frequency change was calculated. On average, 5 correlation coefficients for 11 out of 13 subjects had a negative value. Moreover, all correlation coefficients for 10 of the 13 subjects were negative. A negative correlation coefficient means that the vibration perception became weak; this occurred when

Fig. 1. Experimental setup and environment. (a) The VAI used in the experiment. (b) Experimental environment A vibration motor is mounted inside the vibration device.

the frequency after change was high, even if the vibration frequency after change was the same. On the other hand, a positive correlation coefficient means that the lower the frequency before change, the stronger is the vibration strength perceived by the subjects. The correlation coefficients and experimental results of all subjects are shown in Table 1 and Fig. 2.

Table 1. Correlation coefficients between perception after change and the frequency before change.

Frequency after change	Correlation coefficient
70	-0.93
90	-0.94
110	-0.99
130	-0.98
150	-0.97

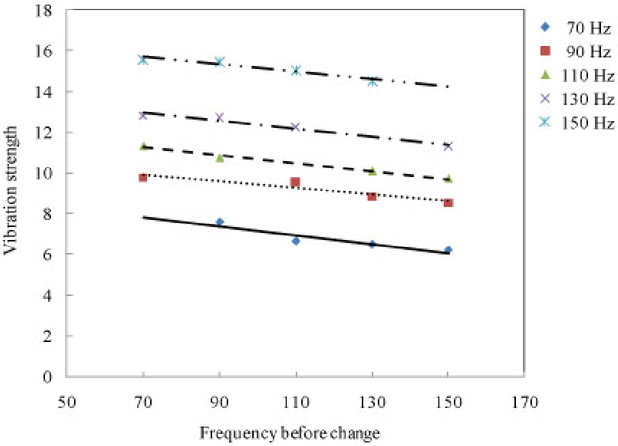


Fig. 2. Change in perceived vibration strength caused by vibration before change

Perceived vibration strength after change was induced by vibration before change, even if the vibratio frequency after change was the same. Subjectts perceived strength 10 when the frequency changed to 110 Hz, from 150 Hz, while subjects perceived strength 12 when the frequency changed to 110 Hz, from 70 Hz.

All correlation coefficients were close to 1.0; however, it was cleary shown that subjects perceived vibration s much more prominently when the frequency before change was low. In Fig. 2, the x-axis represents the frequency before change and the y-axis represents the perceived vibration strength after change. The slope of lines consistently point downward and this also shows how the perceived vibration strength changes with the frequency before the change.

3 KI Model

3.1 Configuration of Arrayed Neurons

In section 2 above, we described our experimental results in which the vibratory adaptation changed the perception of vibration. To convey correct information to a user, the perception gap due to adaptation has to be eliminated. Therefore, we propose incorporating a feedback mechanism for frequency before change into the vibratory adaptation model, as shown in Fig. 3. We chose the KI model as the adaptation model [7].

Fig. 4 shows a schematic configuration of arrayed neuron of the KI model. The KI model consists of excitatory and inhibitory neurons complement one another. An excitatory neuron generates a positive impulse and an inhibitory neuron generates negative impulse. Each receptor is connected with an excitatory and an inhibitory neuron. The two neurons are combined to form a 2nd-order neuron. When a signal input is applied to a receptor, both the neurons generate a nerve impulse and information is captured by the 2nd-order neuron.

3.2 Formulation

A single pulse generated by each of the excitatory and inhibitory neuron is given as

$$u_{\pm}(x,t) = \pm\frac{1}{2}Q_0\frac{R\alpha_{\pm}}{\sqrt{\pi t}}\exp\left(-\frac{\beta_{\pm}}{\alpha_{\pm}{}^2}t-\frac{\alpha_{\pm}{}^2x^2}{4t}\right) \tag{1}$$

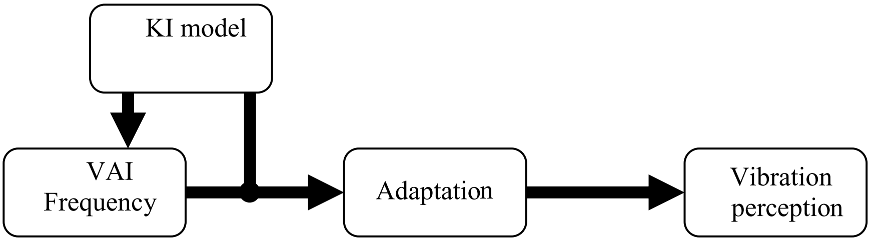


Fig. 3. Correcting the perception gap due to adaptation; the frequency before change is fed back and the VAI vibrates at the corrected frequency as calculated by the KI model

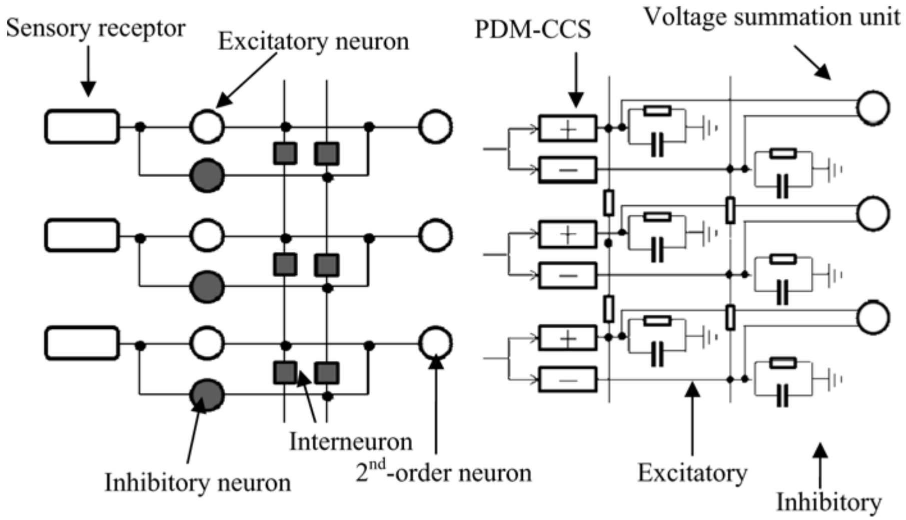


Fig. 4. Configuration of arrayed neurons for KI model and an equivalent circuit

where + and – correspond to the excitatory and inhibitory neurons, respectively, $Q_0 / 2$ shows pulsed current at x = 0, R is the resistance, α is the diffusion speed, and β / α^2 is the attenuation speed. These pulses are accumulated and given at the 2nd-order neuron as

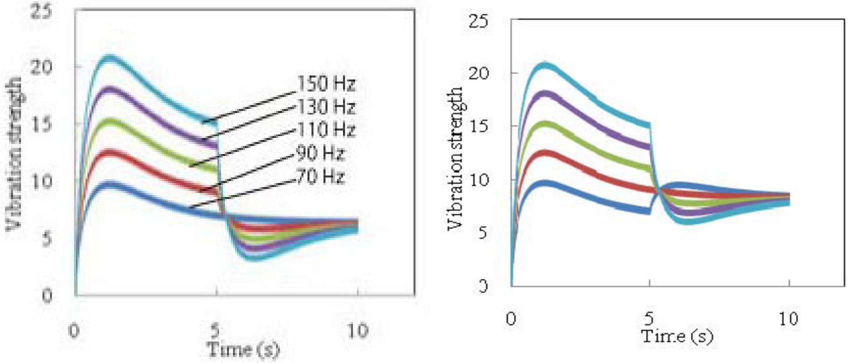
$$u(x,t) = \sum_{i=1}^{N} \left[u_+ (x, t + iT_+ + \tau) + u_- (x, t + iT_-) \right] \tag{2}$$

where τ is the firing time difference between the excitatory and inhibitory neurons, and T is the pulse interval form the sensory receptor.

4 Simulation Using KI Model

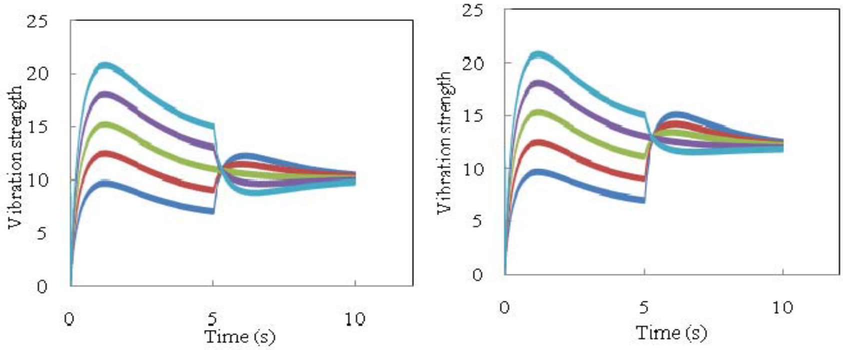
To calculate the correction frequency using KI model, the KI model needs to express the change in vibration perception caused by vibration before change. If the KI model expresses the vibratory adaptation, the correction frequency is calculated using the frequency before change.

We conducted a simulation using KI model to examine the adaptation effect in this KI model. In this simulation, the vibration frequency was input into a sensory receptor, and the output was accumulated at the 2nd-order neuron. This output is taken as the perceived vibration strength. The input frequency changed at the 5-second mark. Our simulation results are shown in Fig.5.



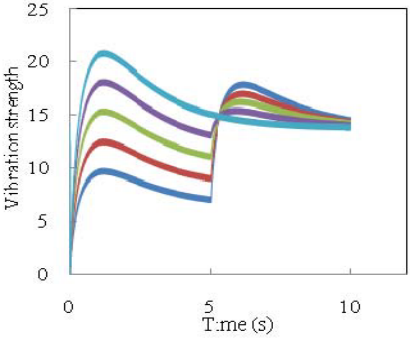
(a) 70 Hz

(b) 90 Hz



(c) 110

(d) 130



(e) 150

Fig. 5. Simulation using the KI model of the change in vibration strength due to the frequency before change. The vertical axis represents the perceived vibration strength after change. The frequency of 70-150 Hz changed to one frequency at the 5-second mark. The vibration strength after the change was changed due to the frequency before change, although the frequency after change was the same. Parameters: $\alpha_+ = 0.58, \alpha_- = 0.30,\ \beta_+ / \alpha_+^2 = 1.05,\ \beta_- / \alpha_-^2 = 0.52$.

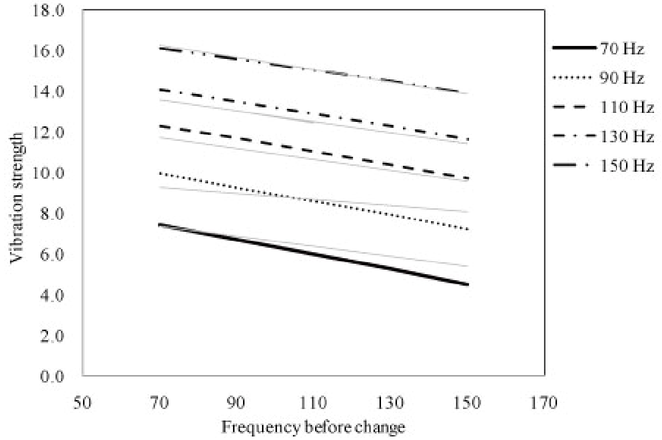


Fig. 6. A comparison of simulation results with experimental results; black lines represent simulation results, whereas gray lines represent experimental results from Fig. 2

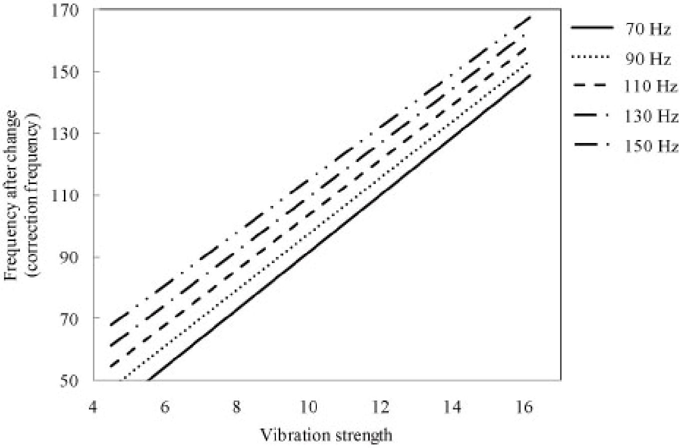


Fig. 7. Correction frequency calculated by the vibration strength and the frequency before change. When the frequency before change is 70 Hz and the VAI wants user to perceive the vibration strength 12, the correction frequency become 110 Hz.

Fig. 5(a) shows that the vibration perception for different values of frequency before change when the frequency after change was 70 Hz. Naturally, the vibration strength before change was different because the frequency before change was different; however, the vibration strength after change was different even though the frequency after change was the same. This is owing to the influence of adaptation, which was also confirmed for other frequencies, as shown in Fig. 5(b)-(e).

Fig. 6 shows a comparison of the simulation results with our experimental results. The slopes of the simulation results point downward similar to our experimental results. Further, the KI model seems to express the adaptation effect, because both sets of results are close to one another. From this simulation, we found that the KI model was able to express the change in vibration perception caused by adaptation.

Using the KI model, we can calculate the correction frequency to eliminate the change in vibration perception due to the adaptation effect because the KI model was able to express the change in vibration perception caused by adaptation. The vertical axis and the horizontal axis from Fig. 6 change to the frequency after change and vibration strength, respectively, we obtain Fig. 7. Fig. 7 shows the correction frequency calculated by the vibration strength and the frequency before change. Therefore, the KI model can calculate the correction frequency by input the vibration strength that the VAI wants to convey and the frequency before change.

5 Conclusion

In this paper, we examined the change in vibration perception by adaptation. We found that vibration perception after change was changed by the frequency before change when the vibration frequency changes. Moreover, owing to the adaptation effect, the higher the vibration frequency before change, the weaker the perceived vibration strength. To correct this effect of adaptation, we proposed a correction method that feeds back the frequency before change to the KI model. We trust that the KI model is able to successfully calculate the correction frequency, because through simulation the KI model successfully expressed the change in vibration perception caused by adaptation. In our future work, we ascertain the effectiveness of this feedback correction by using the KI model in correction experiments.

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