Subjective Correspondence among Visual Variables, Auditory Variables and Duration of Vibratory Stimulus Using Remote Controller

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Subjective correspondence among visual variables, auditory variables and vibratory feedback to a hand was experimentally examined to improve usability of a remote controller. First, we studied the correspondence among visual variables represented on a screen or auditory variables and the duration of vibratory stimulus to the subjects' hand by subjective evaluation. Subjective rating method was used in ten items; suitability, comprehensibility, ease-to-use, naturalness, variety, activity, usualness, interest, wish-to-use and feeling of pleasure. Second, to show the effects of multi-modal interface using visual sense, the sense of auditory and vibratory sense, we combined positive stereotype of visual variables and auditory variables provided with the first experiment. The results showed some stereotype between visual variables or auditory variables and duration of vibratory stimulus. Some of the variables such as size, direction of motion, hue, brightness of color and volume of sound had high correspondence with the duration of vibration.

1. Introduction

Multi-modal interfaces that are used more than one sense such as visual and auditory sense are important to design user-interfaces. The multi-modal interfaces are useful for sense handicapped persons and elders. For example, usability have improved by using the sense of touch [1], [2]. On the other hand, it is important to design the natural interface for transmitting the feedback responce.

Shioyama et al. had been examined whether vibrations to the human hand combined with visual information were more natural for users [3]. This paper aimed at the development of multi-modal interface by visual, auditory and vibratory senses as the feedback. It is to say that stereotype in the vibration whether it becomes natural that auditory-visual information as a feedback. D.A.Norman points out the stereotype that is rather cultural restriction, and the stereotype is useful as a design index of human interface to guide a user [4]. For example, it knows that various stereotypes exist between the operation direction of slider and the rotation direction of the dial and the result [5]. In the experiment I, the correspondence of variables between visual and vibratory stimulus was examined, and then the correspondence of variables between auditory and vibratory stimulus was examined. In the experiment II, the stereotype among visual, auditory and vibratory stimulus was compared with the result of the experiment I.

2. Experiment I: Correspondence between duration of vibratory stimulus and visual or auditory variables

2.1 Methods

Subjective correspondence was examined between the duration of vibration to the hand and visual or auditory variables. These variables were shown in Table1. Auditory variables were volume, pace and tempo. Visual variables were size, rotation, movement direction, color and brightness. The bg, being inside the parenthesis of in the table, shows

background of the CRT screen. The short ⇔ long in this table indicates the change direction of the duration of vibration.

Table 1 Visual and auditory variables

Visual &Auditory Variables		vibratory stimulus short ◄——► long	
size	siz1	small	big
	siz2	big	small
rotation	rot1	left	right
	rot2	right	left
direction of motion (deg)	dir1	180	0
	dir2	225	45
	dir3	270	90
	dir4	315	135
	dir5	0	180
	dir6	45	225
	dir7	90	270
	dir8	135	315
hue	hue1	blue	yellow
	hue2	yellow	blue
	hue3	red	green
	hue4	green	red
brightness of black	bri1	bg(white):darkness	bg(white):brightness
	bri2	bg(white):brightness	bg(white):darkness
	bri3	bg(black):darkness	bg(black):brightness
	bri4	bg(black):brightness	bg(black):darkness
volume of sound	vol1	low	high
	vol2	high	low
pitch of sound	pit1	low	high
	pit2	high	low
tempo of sound	tem1	slow	fast
	tem2	fast	slow

2.2 Apparatus

The weight of the controller was 175g. Vibration motor was fixed on the basic board not to take out fricative sound. The remote controllers used for the experiment is the basic rotation 7500 r.p.m and amplitude 0.03 mm, and three buttons are attached to it as shown in Figure 1. Operational screen was programmed by the software of Director (Macromedia). Switching of vibration motor in the remote controller was made by serial output from the computer. Vibration pattern was generated by change the numerical values of the program.

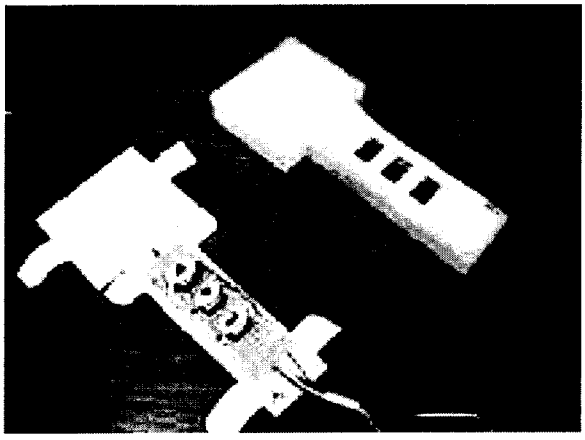

Fig.1 The remote controller produced for the experiment.

The pattern of the vibration was changed as follows according to the objects on screen or the change of the sound. The one cycle of vibration was 1.4 seconds, and duty of vibration was changed from 0.1 to 1.3 seconds by the unit of 0.1 second. The sound frequency of sine wave was 540 Hz. Volume level of the sound was changed from zero to 240 by 20 steps. Pitch of sound was changed from 300 Hz to 780 Hz by step of 40 Hz. Tempo was made with the combination of the on-time and the off-time in one second.

Subjects were 2 women and 18 men from 21 to 24 years old. Subjects was made to operate remote controller freely, and evaluate it about the following ten items, suitability, comprehensibility, ease-to-use, naturalness, variety, activity, usualness, interest, wish-to-use and pleasure, using five steps rating method. The results of the experiment I were shown in according to the result of the experiment II.

3. Experiment II: The effect of the combination of visual, auditory and vibratory stimulus

3.1 Visual and auditory variables

To select suitable combinations of variables from the result of the experiment I, the high score of suitability and the total values were shown in Table 2 and Table 3. Table 2 shows the highest score of suitability and total value was in siz1, rot1, dir3, hue4 and bri2. Furthermore, it is chosen, in the same way, vol1, pit2 and tem1 from Table 3. This group of variable combinations was called Type 1.

The lowest score in visual variables were siz2, rot2, dir8, hue3 and bri1, and the lowest score in auditory variables was vol2. We call this group of variable combinations Type 2. In the experiment II, the above Type 1 and Type 2 variables were used as shown in Table 4.

Table 2 Score of subjective evaluation for visual variables

visual variable	subjective score		visual variable	subjective score	
	suitability	total		suitability	total
siz1	4.2	34.3	siz2	2.4	28.1
rot1	2.9	31.3	rot2	2.9	28.0
dir1	3.1	30.7	dir5	2.8	29.0
dir2	3.2	31.8	dir6	3.0	29.4
dir3	3.5	32.8	dir7	3.2	30.8
dir4	2.9	27.0	dir8	2.7	27.4
hue1	2.6	29.2	hue3	2.6	28.8
hue2	2.8	30.1	hue4	3.5	31.7
bri1	2.9	29.6	bri3	3.1	31.0
bri2	3.6	32.1	bri4	3.2	30.4

Table 3 Score of subjective evaluation for auditory variables

auditory variables	subjective score		auditory variables	subjective score	
	suitability	total		suitability	total
vol1	3.8	33.4	vol2	2.4	27.7
pit1	3.1	32.5	pit2	3.4	33.4
tem1	3.1	30.9	tem2	2.7	30.3

Table 4 Audio-visual variables

Type	Name of variable	Audio-visual variable	
Type1	s1-v1	siz1	vol1
	s1-p2	siz1	pit2
	s1-t1	siz1	tem1
	r1-v1	rot1	vol1
	r1-p2	rot1	pit2
	r1-t1	rot1	tem1
	d3-vi	dir3	vol1
	d3-p2	dir3	pit2
	d3-t1	dir3	tem1
	h4-v1	hue4	vol1
	h4-p2	hue4	pit2
	h4-t1	hue4	tem1
	b2-v1	bri2	vol1
	b2-p2	bri2	pit2
	b2-t1	bri2	tem1
Type2	s2-v2	siz2	vol2
	r2-v2	rot2	vol2
	d8-v2	dir8	vol2
	h3-v2	hue3	vol2
	b1-v2	bri1	vol2

3.2 Methods

The experimental approaches, the subjective evaluation, the apparatuses and subjects were the same as the experiment I.

4. Results and discussions

The results on subjective evaluation of size, rotation, movement direction, hue and brightness of the experiment I and II were shown in Figure 3 to Figure 7 respectively. Furthermore, the result of the experiment I about the auditory variables was shown in Figure 8.

4.1 Results of the experiment I

Change of size:

Figure 3 showed that high score was obtained when the duration of vibrator stimulus became long according to enlarge the size in all evaluation items. Specially, significant differences were revealed in suitability, ease-to-use and naturalness. This brings the sense that vibration becomes large when duration of vibration becomes long, and it coordinated with the image of the size expansion of the objects.

Rotation:

Figure 4 showed that the total score of rot1 was a little higher than that of rot2. The rot1 of the evaluation in each item was higher than the other items except for the change item. Few differences, however, was seen about the suitability. In ordinal offices, the volume operations in dial-type input devices were made so that value may become big as much as to turn it clockwise. However, the effects

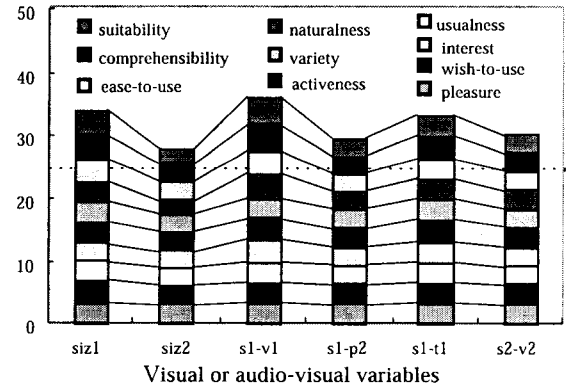

Fig. 3 Subjective evaluation with size

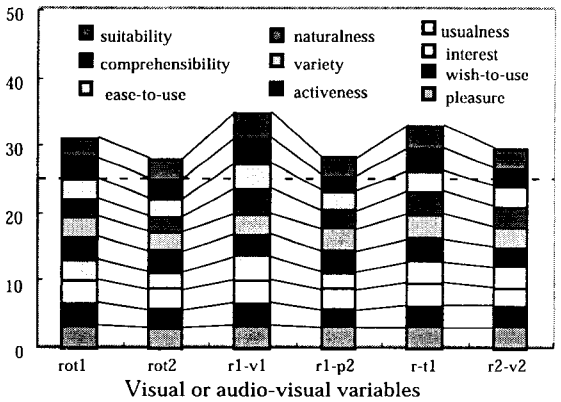

Fig. 4 Subjective evaluation with rotation

were not suggested to all subjects by the feedback of the vibration.

Movement direction:

The total evaluation of dir1, dir2, dir3, dir7 was high in comparison with others as shown in Figure 5. It was suitable that duration of vibration becomes long when object moves dir1, dir2, dir3 in the direction where the value of x and y coordinate increases. We have the stereotype strongly in the daily life that a value becomes big when a mark and index move from bottom to top or from left to right. Therefore we can estimate this stereotype brought the difference to the subjective evaluation.

However, dir7 didn't correspond with the stereotype at the daily life because duration of vibration became long when objects were moved from the top to the bottom on the screen. Furthermore, dir3 had obtained highest score in suitability, comprehensibility, ease-to-use and naturalness that were important to find good stereotype.

We could introduce from the above results that it was natural for users to combine the vibration with the movement in the vertical direction. And, short duration of vibration was most suitable for users when objects were moved to the bottom direction, and long one was most suitable when moved to the top.

Change of hue:

Figure 6 showed high score of hue4 in total evaluation values, ease-to-use, suitability and naturalness. These indicate that users' feelings coordinate that the color of object changes red as duration of vibration becomes long. The same differences, however, in items except for it were hardly seen. Moreover, the total evaluation of hue3 was the lowest, and vibration was not suitable for the change in red-green. The vibration connected with the improvement of the operation was not found in all change of hue.

Change of brightness:

In the total score, bri2 obtained the highest value and bri1 the lowest ones in figure 7. However the differences between them were very small. The differences between bri2 and bri1 appeared greatly at suitability.

It is general to turn a dial clockwise when lighting level will be high. Relation between lighting level and duration of vibration was supposed to be consistent. However it became a contrary result in brightness. The reason of this result was considered that object

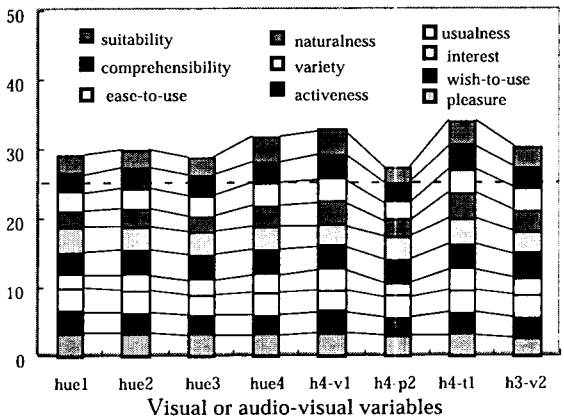

Fig. 6 Subjective evaluation with hue

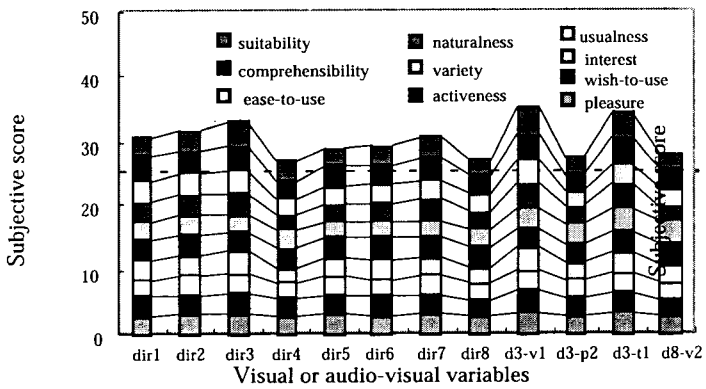

Fig. 5 Subjective evaluation with direction of motion

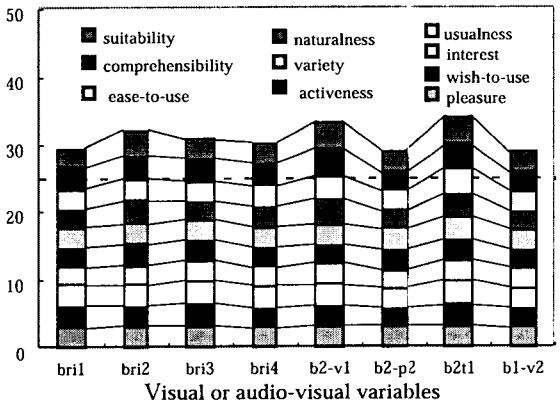

Fig. 7 Subjective evaluation with brightness of color

color melted into the white background when object grew light. Therefore subjects felt the existence was little gradually. So, it was examined in the case of black background. However it was hardly seen as for the differences in bri3 and bri4 in comprehensibility from figure 7. It is natural correspondence that the direction that the objects color changes dark gradually and which duration of vibration becomes long when background is white.

Change of volume:

Figure 8 showed that the score of vol1 was higher than vol2 in all items. The feedback against the increase in the volume corresponded strongly with the longitude of the duration of vibration. This is thought to imagine the high amplitude of vibration in increasing duration of vibration. The same tendency was revealed in relation between visual variables and size or rotation.

Change of pitch and tempo:

The great differences of subjective score were not obtained in Figure 8, though the total score of pit2 was slightly higher than pit1 and that of tem1 was higher than tem2. The relation between sound levels that become great and duration of vibration that increases were highly corresponded in the total score, suitability and comprehensibility. Moreover, the association between the direction of tempo that becomes fast and duration of vibration that increases was consistent.

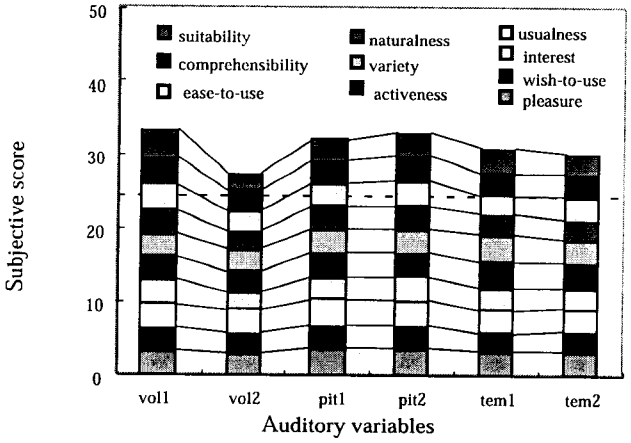

Fig. 8 Subjective evaluation with volume, pitch, and tempo

4.2 Result s of the experiment II

Type1:

In the size, the rotation, the movement direction, the score of s1-v1, r1-v1, d3-v1 was the highest as shown in Figure 3, Figure 4 and Figure 5. It was proved that the feedback of the vibration acted more effectively when these three kinds of variables were combined with the volume. Score of rotation was most raised in giving volume compared with only visual variables. Users were accustomed to turn dial clockwise for increasing volume of sound, therefore, such multiplier effect was produced.

Moreover Figure 6 and Figure 7 showed that the scores of h4-t1 and b2-t1 were very high in color and brightness. Combination of suitable tempo, hue and duration of vibration gave the most consistent feeling to users. On the other hand, the multiplier effect of the combination with pitch and vibration was small. The score decreased by adding pitch except for the rotation. This suggests the following reasons. First, some users felt that long duration of vibration was consistent with low level of sound because a feeling of the weight increases by the low sound presser. On the other hand, some users felt that the short duration of vibration was consistent to the small volume occurred by low amplitude. In the case of the former, visual and vibrator sense were consistent with each other. However, it considered that there were imbalance connections between visual and auditory sense and between auditory and vibrator sense. These imbalances induced low scores.

Type 2:

Though the differences of the total score were a little, s2-v2 was bigger than siz2 as shown in figure 3.

Other visual variables showed the same tendency in figure 4 to figure 7. The reason of raising the scores was considered that visual variables were consistent with auditory variables. However vibration as a feedback was not consistent with two variables. Therefore, large multiplier effect in Type 2 could not

obtaine.

5. Conclusions

In order to introduce vibration as the feedback in machine operation, the duration of vibration and visual variables or auditory variables were examined about subjective correspondence. Furthermore, the multiplier effect was examined when vibratory, visual and auditory senses were unified.

Following conclusions were obtained.

(1) The increase of the duration of vibration was highly consistent in the case that objects become big.

(2) There was little effect of the vibration in the rotation movement though the increase of duration of the vibration corresponded to the right rotation compared with the left rotation.

(3) The movement direction zero to 90 degrees of the object coped with increase in duration of vibration well.

(4) A change to the red of object color coordinated with the increase in duration of vibration.

(5) Consistency between dark light and short vibration was high.

(6) High score was obtained by adding long duration of vibration when sound becomes loud.

(7) Good correspondence between pitch and vibration was shown in the case of increasing duration of vibration when pitch was become low.

(8) Though the increase in duration of vibration coped with the direction where the tempo of the sound became fast. There was not significantly difference from the direction which tempo becomes late.

(9) When volume was fitted to the size, the rotation and the movement direction, the feedback of the vibration was effective. Moreover, the effect in the combination with rotation and volume was especially the highest.

(10) Good visual variables coordinated with pitch were not pointed out.

(11) Though the auditory sense was only consistent with the visual sense, users felt unnatural by adding unsuitable vibrations.

If it was used to coordinate three modalities of the visual, auditory and vibratory sense with each other, it became a better stereotype rather than the case of two modalities. And it was proved that the operation could be improved.

6. Summary

To show a good stereotype in operation of remote controller, this paper examined the duration of vibration combining with what kind of visual or auditory information. Then easy-to-use and natural coordination between these modalities was revealed. Furthermore the effects of multi-modal interface by using visual, auditory and vibratory stimulus were shown. Though feedback signals, operation and conformity were evaluated subjectively, it will be examined on the objectivity evaluation of the operation using visual, auditory and vibration as the feedback.

References

[1] A.Kimura, S. Ryumae and M. Shimizu: Development of vibrotactile display to offer time depending information, *The 13th Human Interface Symposium*, 161-166 (1997)

[2] M.Kawakami et al.: Development of touch-sensitive displays with various tactile, *The 13th Human Interface Symposium*, 299-304 (1997)

[3] A.Shioyama et al.: Subjective compatibility between duration of vibratory stimulus to a hand and visual variables, *Human Interface News & Report*, Vol.13, 345-350 (1998)

[4] D.A.Norman: The Psychology of Everyday Things, BasicBooks (1988)

[5] A.J.Courtney: Control-display stereotypes for multicultural user systems, *IEEE Trans. Systems, Man, and Cybernetics*, Vol. 22, 681-687 (1992)