Slow Motion Replay of Tactile Sensation

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ABSTRACT

The use of slow motion is already well established, and we daily enjoy the visual effects of slow motion content. Slow motion techniques are not only useful in scientific research, but also provide new possibilities in the fields of art and entertainment.
We believe that tactile sensation can also benefit from the effect of slow motion replay. In this paper, we report on the system we developed and the results of experiments to confirm the "emotional effect" and the "ability to discriminate" in tactile slow motion.

KEYWORDS: Tactile Sensation, Slow Motion Replay, Collision

INDEX TERMS: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O; H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1 INTRODUCTION

A technique of expanding information in a time-wise manner has already been widely used, not only for the analysis of high-speed phenomena, but also for art and entertainment. Slow motion is already a popular visual effect in many movies, and gives us new perceptions [1]. However, this time expansion technique is currently limited to visual information. In the case of audio information, simple time expansion results in odd or inaudible sound. Then, this technique can be used only several situation such as dance training.
The time expansion of tactile information raises some interesting issues. We believe that with tactile sensation, the slow motion effect may provide some useful benefits for the following reasons. When we stroke a textured material with our hands, we can generally recognize the texture of the material irrespective of the stroking speed. Furthermore, research has developed tactile displays which respond to hand movements[2][3]. This suggests that it is possible to use the effect of time expansion in acquiring tactile information.
In this paper, we describe a recording and replay system to realize tactile slow motion. We also show two experiments to establish the effectiveness of tactile slow motion, taking collision phenomena as examples, since collision observation is one of the most popular situations in visual slow motion content.

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2 METHOD AND SYSTEM

2.1 Method of Tactile Stimulation

In our tactile presentation method, the user holds a speaker with his/her hand and an elastic band around the circumference of the speaker cone seals the air between palm and cone (Figure 1). If the cone of the speaker is pushed, the user feels a pushing force because the air pressure between cone and palm is increased. If the cone is pulled, the user feels a suction force because of the decrease in the air pressure. By controlling the frequency and amplitude, the sys-tem can present varied tactile sensations.

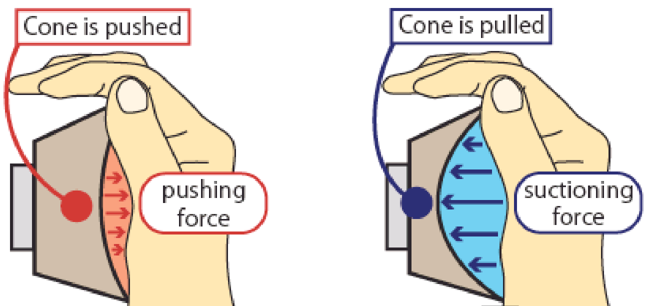

Figure 1. Tactile presentation method [4]

There have been many proposals that used air pressure [5][6], but they were generally plagued by problems with limited frequency bandwidth because of thin tubes and electric valves. We avoided this problem in a simple way, by very close collocation of the palm and the speaker.
We already made a prototype in accordance with this method, and confirmed that our system has an enough potential of presenting tactile sensation (pressure is 1.4 kPa or more) by pilot study [7].
Our method has three main advantages for the presentation of a rich tactile feeling.
The first is a wide temporal bandwidth. We used a general speaker for our tactile device, because a speaker has a very wide temporal bandwidth (from under 1 Hz to 20 kHz). Therefore, we can present varied tactile information with changing frequency and amplitude. In addition, by using a composite waveform of the tactile area (low frequency) and the sound area (high frequency), our system can present multimodal (both tactile and sound) sensations easily. This advantage has already been achieved by haptic displays [8][9][10]. These merits are important aspects of varied tactile experiences, and may broaden the application area.
The second is uniform tactile sensation. In the case of a mechanical tactile display, solid moving pins contact and distort the skin. As the spatial distribution of the distortion is not uniform, users experience a sensation of "shape", which is both unnecessary and cumbersome information for our purposes. Conversely, our method presents purely uniform pressure to the

palm, and the user feels only that pressure without any feeling of edges or shape.

The third is positive and negative pressure presentation. Our method can present suctioning force, as well as pushing force. Most tactile displays used vertically moving contactors that push the skin, while some works focused on tangential force [11][12][13]. However, there were few trials that presented suctioning force [14].

2.2 Principle

The principle of tactile slow motion is quite simple. First, the tactile phenomenon is recorded with a high sampling rate. Next, a tactile display replays the recorded data with a different sampling frequency. For instance, if the recording is at a 50 kHz sampling frequency and replay is at 5 kHz, the user can experience a 10 times slower tactile sensation.

2.3 Recording System

The recording system is composed of a laser displacement meter (KEYENCE CORPORATION, LK-H50), a high speed camera (CASIO COMPUTER CO., LTD., EXILIM EX-F1), a plastic board (thickness=1 mm) and a PC (Figure 2).

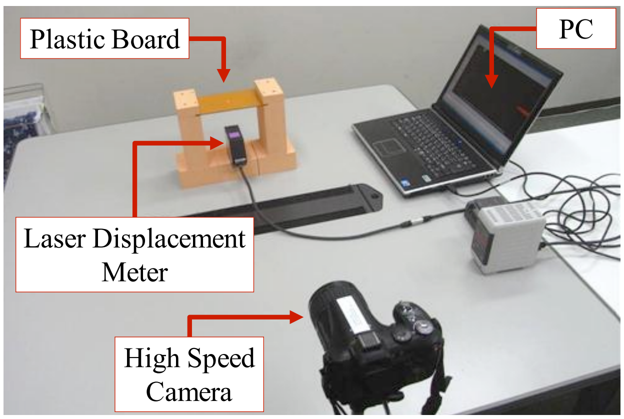

Figure 2. Recording system

Objects fall onto the plastic board, and the system records the vibration caused by the collision (Figure 3). The sampling rate of the displacement sensor is 100 kHz, and the sampling rate of the camera is 1200 fps (frames per second).

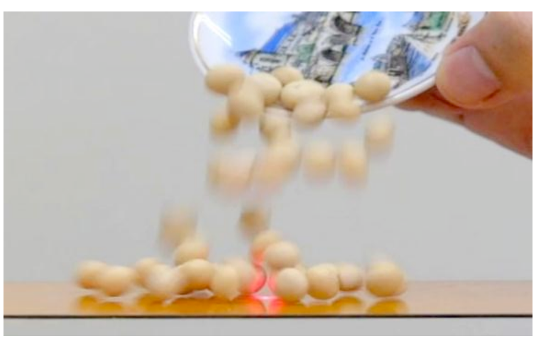

Figure 3. Objects fall onto the plastic board

2.4 Replay System

The replay system is composed of a tactile display, an LCD display, a stereo amplifier (RASTEME SYSTEMS CO., LTD., RSDA202), a D/A board (Interface Corporation, PCI-3523A) and the PC (Figure 4).

The tactile display is composed of an audio speaker that faces downwards. The user covers the speaker with his/her palm while the speaker vibrates air between the speaker and the palm. The user feels the suction and pushing sensations on his/her palms from the air pressure (Figure 5, Figure 6).

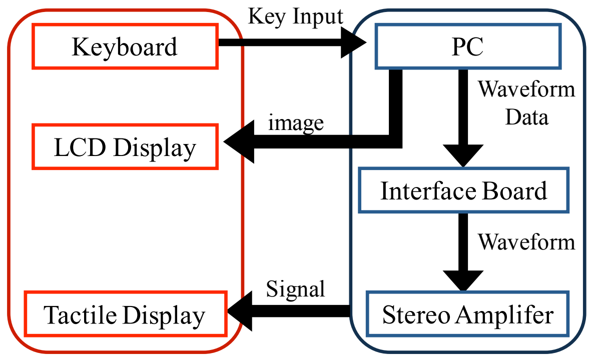

Figure 4. Overview of replay system

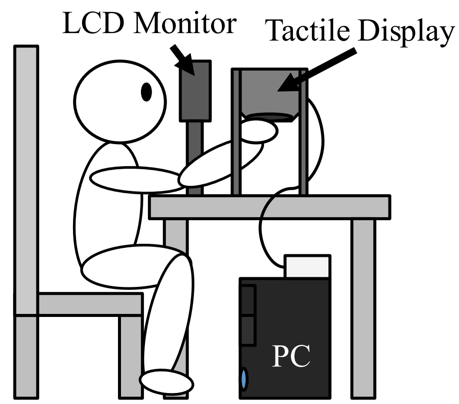

Figure 5. System Setup

Figure 6. Scene of experience

3 Experiment 1: Subjective Evaluation

As a first experiment, we conducted a subjective evaluation of the slow motion tactile sensation by means of a questionnaire. The procedure of the experiment was as follows:

- *The participant experienced normal speed and slow motion replay (40 times slower). Only visual information was presented (Case 1).*
- *The participant experienced normal speed and slow motion replay (40 times slower). Tactile and visual information were presented (Case2).*
- *The participant was asked to answer the relative impressions of Case 2 compared with Case 1, by rating seven selected terms on a scale of 1 to 5, where 1 means much lower than Case 1, 3 means the same and 5 means much higher.*

The selected seven terms are adjectives that are frequently used to express reactions to visual slow motion effects. Prepared objects were "small bottle", "screws" and "silicone". Thirty eight participants (12 males, 27 females, aged: 10-30's) participated in the experiment.

Figure 7. Prepared objects
Left: bottle Center: screws Right: silicone

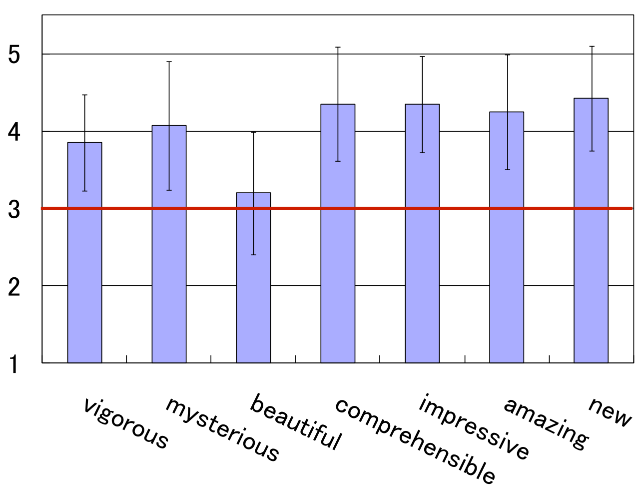

Figure 8. Experiment 1: Selected seven terms and rating

Figure 8 shows the results. From the graph, all terms were higher than 3. In particular, the ratings of "comprehensible", "impressive" and "new" were quite high. From the results, we confirmed that there certainly is an "emotional effect" in tactile slow motion.

4 Experiment 2: Sample Discrimination

Experiment 1 featured a combination of tactile and visual. Then next experiment featured only tactile. We focused on the high rating of "comprehensible" in Figure 8 and considered that tactile slow motion provides an ability to discriminate. Therefore, we conducted an experiment on sample discrimination. The procedure of the experiment was as follows:

- *Before the experiment, the participant experienced a feeling of collision by using the recording system, and watching a collision video that was shot during the recording of tactile phenomena.*
- *The participant then experienced replayed tactile collision data of the samples by using system, and chose the name of the sample from a prepared list.*

In this experiment, we prepared four replay speeds (normal, 3, 10, 30 times slower), and chose nine samples. The selected samples were classified into three categories depending on physical property, size and shape. The samples and scene of the experiment are shown in Figure 9. Each sample was presented five times randomly at each replay speed. While participating in the experiment, participants put on headphones and listened to white noise to block off audio information. Eight participants (eight males in their 20's) participated in the experiment.

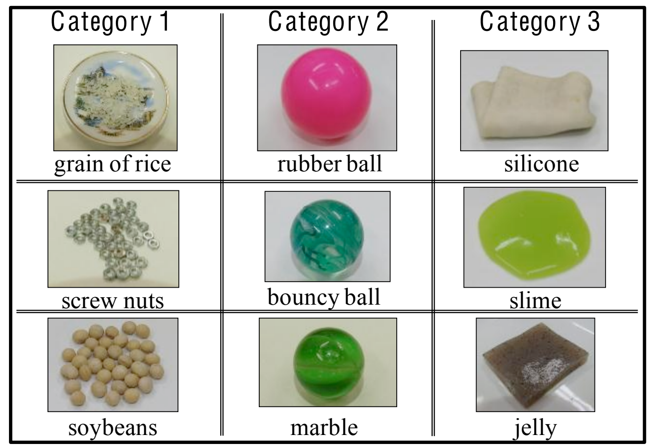

Figure 9.Selected samples

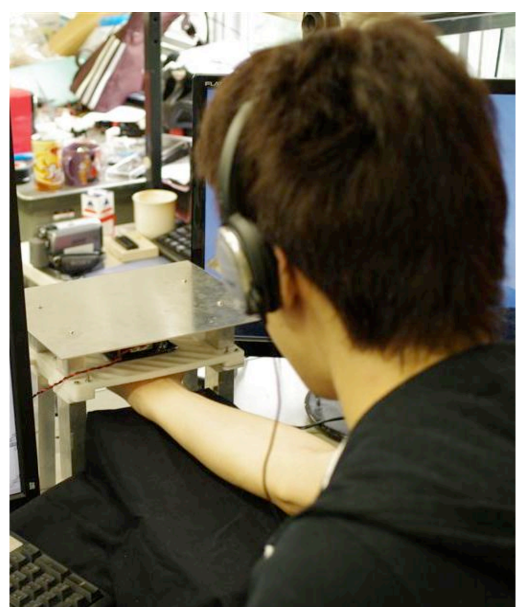

Figure 10. Scene of experiment

Results of experiment are as follows.

:the highest rate

:the second highest rate

1: grain of rice 2: screw nuts 3: soybeans
4: rubber ball 5: bouncy ball 6: marble
7: silicone 8: slime 9: jelly

Figure 11. Annotations of tables of results

Table 1. Average of answer rate (normal)

Presented Sample	Average of Answer Rate [%] 1	2	3	4	5	6	7	8	9
1	50	8	3	0	3	5	15	15	3
2	18	23	30	3	10	13	0	3	3
3	5	48	35	3	8	3	0	0	0
4	0	3	0	40	33	25	0	0	0
5	0	3	3	33	28	35	0	0	0
6	0	0	0	38	33	30	0	0	0
7	0	0	3	3	0	3	33	28	33
8	5	0	3	3	0	5	20	48	18
9	0	0	0	8	5	3	28	20	38

Table 2. Average of answer rate (3 times slower)

Presented Sample	Average of Answer Rate [%] 1	2	3	4	5	6	7	8	9
1	60	3	3	0	3	0	13	18	3
2	20	30	28	10	5	5	0	3	0
3	5	35	25	10	8	5	3	8	3
4	0	3	5	43	38	10	3	0	0
5	0	3	3	45	23	20	5	0	3
6	0	5	3	35	33	18	5	0	3
7	0	0	0	0	0	3	38	38	23
8	0	0	3	3	5	5	23	35	28
9	0	0	0	5	5	5	20	25	40

Table 3. Average of answer rate (10 times slower)

Presented Sample	Average of Answer Rate [%] 1	2	3	4	5	6	7	8	9
1	65	5	3	0	0	0	10	13	5
2	23	50	28	0	5	0	0	0	0
3	5	40	43	0	8	5	0	0	0
4	0	0	0	25	45	33	0	0	0
5	0	0	0	33	33	33	3	0	0
6	0	0	5	55	15	25	0	0	0
7	3	3	5	5	5	0	18	43	18
8	0	3	0	3	0	3	40	28	25
9	0	0	3	10	8	5	10	23	43

Table 4. Average of answer rate (30 times slower)

Presented Sample	Average of Answer Rate [%] 1	2	3	4	5	6	7	8	9
1	50	18	8	3	0	0	8	8	8
2	10	23	30	13	10	8	8	0	0
3	8	25	40	15	8	3	0	0	3
4	0	5	10	35	30	10	5	3	3
5	0	3	3	28	20	35	8	0	5
6	0	0	3	30	35	18	8	3	5
7	20	0	3	0	0	10	25	28	15
8	18	5	5	5	3	8	15	23	20
9	8	5	3	8	5	8	23	33	10

Table 5. Average of correct answer rate of nine samples

Replay Speed [times slower]	Average of Correct Answer Rate [%] 1	2	3	4	5	6	7	8	9	total
1	50	23	35	40	28	30	33	48	38	36
3	60	30	25	43	23	18	38	35	40	34
10	65	50	43	25	33	25	18	28	43	36
30	50	23	40	35	20	18	25	23	10	27

Table 6. Average of correct answer rate of three categories

Replay Speed [times slower]	Average of Correct Answer Rate [%] category 1	category 2	category 3	total
1	36	33	39	36
3	38	28	38	34
10	53	28	29	36
30	38	24	19	27

Table 1 through Table 4 show average answer rates for each sample with different replay speed (1, 3, 10 and 30 times slower). As the diagonal components are apparently large, we can say that it is possible to discriminate samples in spite of different replay speed.

Table 5 shows average rate of correct answer. Interestingly, "10 times slower" scored the highest correct rate, followed by "Normal" and "3 times slower". From these results, it seems that tactile slow motion has a possibility of improving the ability to discriminate objects.

Table 6 shows average of Table 5 for each category. We can see that each replay speed has certain characteristics. In case of category 1, the rating of "10 times slower" was prominent among others. In case of category 3, the rating of "3 times slower" was the highest rating among slow replays. Though the overall ratings of "30 times slower" were low, it was higher than that for normal speed in category 1.

We consider that these differences were caused by the different frequency components of the tactile data. Figure 12 through Figure 14 show the frequency spectrums of three categories. From these graphs, the spectrum patterns were different between categories. In case of Figure 12 (category 1), the peak was localized in around 100 Hz, whereas in case of Figure 13 (category 2), it was broadened between 10 Hz and 100 Hz. In case of Figure 14 (category 3), it was localized under 10 Hz.

Note that slow motion means to shift the graph leftward It is understood that the rate of correct answers were improved by selecting the optimal replay speed and shifted the spectrum so that we can perceive using full bandwidth of innate tactile sensing mechanism.

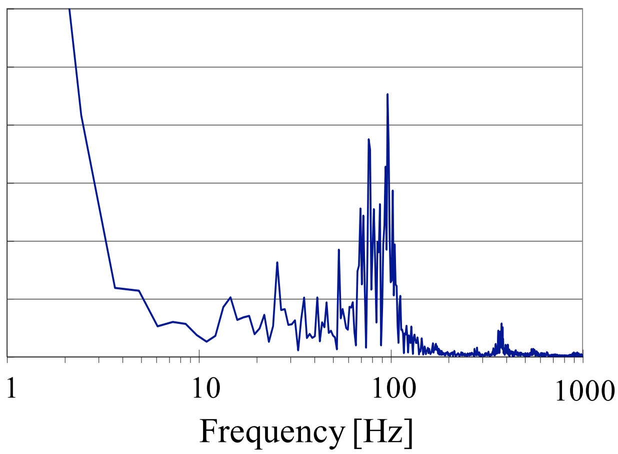

Figure 12. The power spectrum of recorded data Soybeans (category 1)

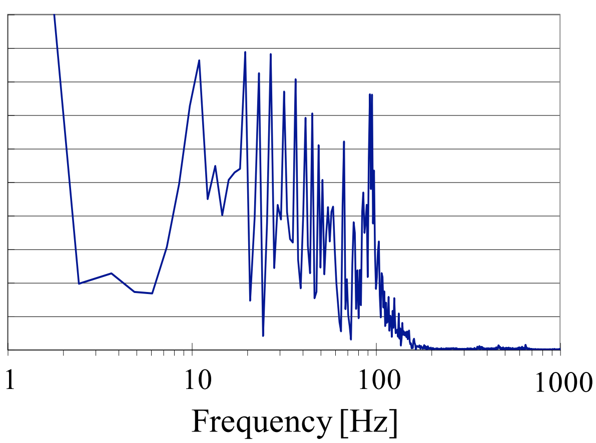

Figure 13. The power spectrum of recorded data Rubber ball (category 2)

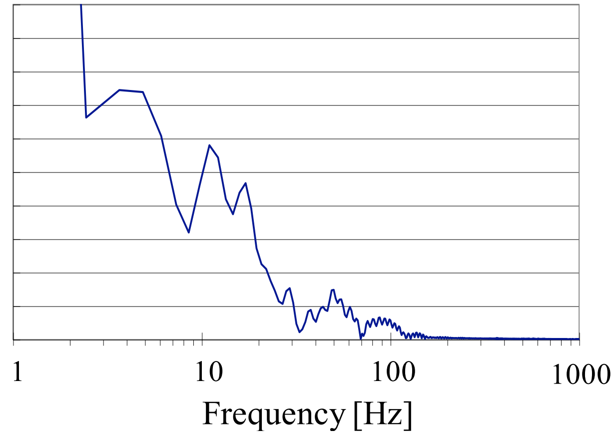

Figure 14. The power spectrum of recorded data Silicone (category 3)

In conclusion, we confirmed that tactile slow motion surely has an ability of discrimination.

5 Conclusion

In this paper, we proposed a new application field for tactile display, "slow motion", and confirmed that tactile slow motion has a similar effect to visual slow motion.

After describing the possibility of the slow motion effect in sensing tactile information, we introduced a recording and replay system to realize experimental tactile slow motion. The replay system utilized our original tactile display that supported a wide frequency range.

We conducted two experiments to confirm the effective-ness of tactile slow motion. One was composed of a combination of tactile and visual slow motion, and the emotional effect was observed. The other was solely composed of tactile slow motion, and the ability to discriminate was evaluated. These two effects were quite common in visual slow motion, since visual slow motion is used to observe and analyze high-speed phenomenon, as well as to enhance perceptions.

From these results, we conclude that the tactile slow motion has new potential. As a next step, we will try to develop an appropriate system for art and entertainment. We will also determine the correlation between discrimination ability and replay speed.

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