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Measuring Visio-Tactile threshold for Visio-Tactile Projector

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Abstract: This paper proposes a new device, Visio-Tactile Projector (VT Projector). VT Projector is a projector which can project both visual image and tactile stimulation on human skin at the same time. For the design or applications of VT Projector, we measured Visio-Tactile threshold (VTT) in three movement patterns and two vibration frequencies by constant method. VTT is the distance on the skin that is required for people to recognize the difference of two stimulated points between projected visual point image and a tactile stimulation. The results showed the VTT is about 10 to 13mm regardless of the stimulate pattern.

Keywords: Visio-Tactile threshold, Visio-Tactile Projector, Cross-modal, Virtual reality, Airborne ultrasound tactile display.

1. INTRODUCTION

In this paper, we propose Visio-Tactile Projector (VT Projector): a projector which can project both visual images and tactile stimulation on human skin at the same time. Our VT Projector proposed here utilizes airborne ultrasound to produce stimulation via air not interfering with visual image. As Harrison et al. presented in "Skinput" [1], a human skin can be a projector screen and used for interfaces. However, usual projector can project only visual images. If projectors can project not only visual images but also tactile stimulation, the method to project on human skin can be used in more various ways. VT Projector gives us new experiences of entertainment, communication, and human behavior guidance.

In addition to the proposal, we measure "Visio-Tactile Threshold (VTT)" defined in this paper. VTT is the minimum distance on the skin that is required to recognize the position difference between a projected visual point image and a tactile stimulation. VTT is one of the fundamental parameters that determine the required specification of VT projector. The procedures and experimental results of VTT are presented.

2. RELATED RESEARCH

One of the most well known researches about tactile resolution is two-point threshold. Two-point threshold is the minimum distance in which humans can feel two distinct points when touched by two nearby objects. Two-point discrimination is widely used in tactile researches and referred in designing tactile tools. According to Stevens' report [2], the experiments tested to subjects in twenties showed that two-point threshold at palm is about 10mm and that at finger is 2-3mm.

Our interest in this paper is sensitivity to the positional difference between visual and tactile stimulations. Weinstein's report [3] and Green's report [4] give clue of these questions. Weinstein examined the error of tactile localization. He gave a subject a tactile stimulation point and after that a next stimulation point near the first point. Subjects judged if the two points were the same place or not. In measuring Two-point threshold, two points are usually presented at the same time but Weinstein did by turns. He discovered the error of localization at fingers or palm is about half of two-point threshold at the same parts.

Green discovered the length measured by tactile and by vision are not same. He showed two-point stimulation with rods and asked subjects to answer the distance of the stimulated points or to draw the stimulated points on a paper. The results showed that the distance measured by tactile tends to become shorter than that by vision.

Weinstein discussed the ability of tactile localization and Green did one of the relationships between vision and tactile. However, these results cannot calculate VTT because, in Green's experiment (or most tactile experiments), subjects are required to their eyes closed during stimulation in order not to get some information by vision. VTT is measured for engineering applications which use mixture of vision and tactile. Therefore, VTT has to measured in the set up in which subjects can open their eyes while experiments. Weinstein's research seems to answer this, but this threshold is measured by tactile-tactile pair, not vision-tactile pair.

At least in our knowledge, there are no researches to estimate VTT.

3. PROPOSED SYSTEM

The VT Projector is composed of two components: Airborne Ultrasound Tactile Display (AUTD) and an image projector. The appearance of the whole set up is shown in Fig. 1. AUTD is an essential component to generate tactile sensation on human skin in a non-contact way. AUTD used in this experiment includes 256 ultrasound transducers put 16 x 16 arrays and generates a spot of focused ultrasound pressure at 40 kHz by controlling transducers' phase [5]. The spot size is about 1cm in diameter, and the max pressure this AUTD can make is 1.5gf.

The image projector used in this experiment is a commercially available projector (Pico projector, Optoma PK320). The projector is attached to the top

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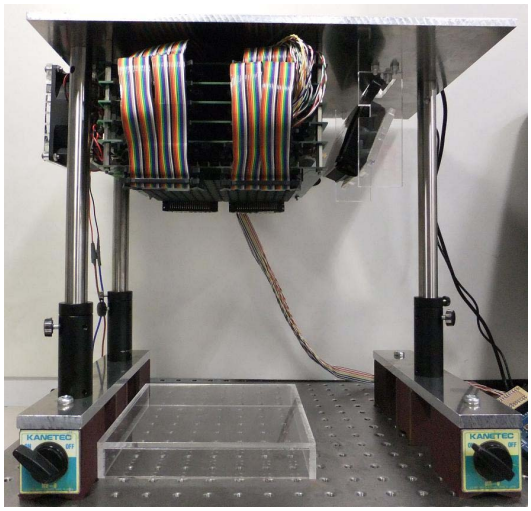

Fig. 1 The appearance of the whole system

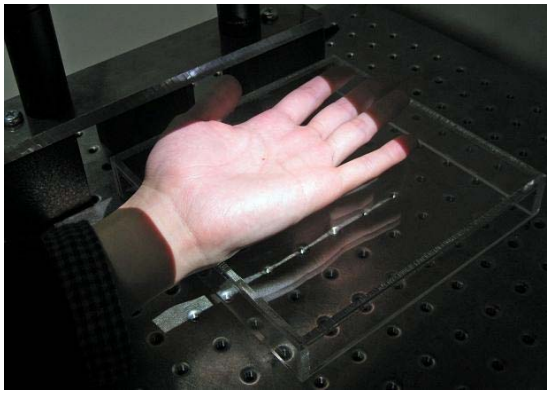

Fig. 2 The picture of experiments. The red point on the palm is the visual stimulation. Tactile stimulation cannot be seen.

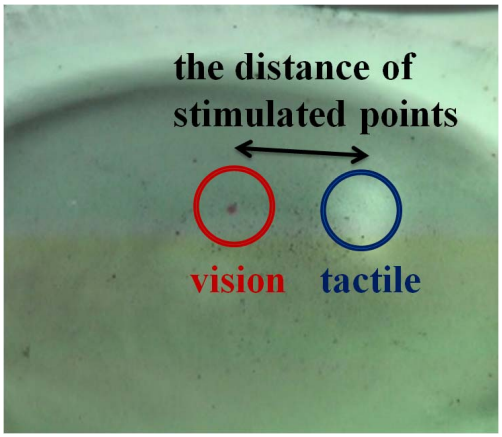

Fig. 3 The picture of stimulated points. The dark red point surrounded in dark red line is the visual stimulus and the white area surrounded in dark blue line is the tactile stimulus. This picture is taken in the scene that AUTD and image projector project simultaneously to a white plate in which oil colored with a black dye is spread thinly. Therefore, AUTD's output looks white because of excluding black oil. In this picture, the stimulated points are shifted on purpose.

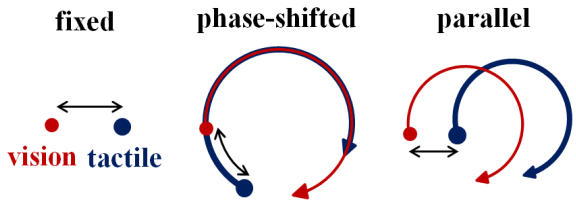

Fig. 4 The patterns of stimulation. The distance is determined as the length of black arrow. The distance is kept while stimulating. The diameter of "phase-shifted" is 32mm, and that of "parallel" is 17mm. They rounds 2 times in 3 seconds.

board slantingly in order to project just under AUTD's array.

4. EXPERIMENTS

4.1 Experimental procedure of VTT measurement

We examine VTT by constant method. All 6 subjects are male and around 25 years old. We project a red point by image projector and a tactile stimulation point by AUTD at the same time on the subjects' palm of the hand. The two stimulating points are shown at the same place or separated places (Fig. 3). The subjects answer the two points are shown at the same place or not. The position shift distances are 6 steps: 0, 5, 10, 15, 20, 25mm. We show these stimuli to each subject randomly 30 times. Therefore, subjects answers 180 times in total. In order to clarify the dependence on the stimulation frequencies, we modulated projected radiation force at 200Hz or 30Hz. 200Hz vibration is considered to mainly stimulate Pacinian corpuscle and 30Hz Meissner's corpuscle [6]. In addition, we tested 3 stimulation patterns: stimulating fixed points, circular motion I (phase-shifted), and II (parallel) as shown in Fig. 4. Therefore, we tested 6 kinds in total. In all tests, the stimuli are shown 3 seconds.

4.2 Results and Discussion

The results are shown in Table 1 and Table 2. We plot the ratio of answer, "The places are the same.", and drew fitted curve by cumulative normal distribution in Fig.5. The numbers shown in Table1 are the position shift distance by which the subjects answered "yes" in half chance. Therefore, these numbers are VTT. The mark "*" indicates rejected case where the ratio of "yes" answer are less than 0.8 even when the visual and tactile points are identical.

Table 2 also shows VTT, but they are adjusted by Abbott's formula [7] [8]. According to Abott's formula, the threshold Φ is calculated by the equation $\Phi = (1\text{-}Pg+Pl)/2$. Pg is called guess rate. In this paper, (1-Pg)

Table 1 The result of Visio-Tactile threshold (mm). A, B, C… are the subjects name. "*" means an inappropriate result where the ratio of answer yes is less than 0.8 at 0mm. Therefore, they are excluded in calculating mean and S.D..

subjects	A	B	C	D	E	F	mean	S.D.
fixed 200Hz	10.00	8.63	9.38	10.59	10.06	13.91	10.43	1.834
fixed 30Hz	9.36	8.87	8.10	12.79	0.96*	10.14	9.85	1.803
phase-shifted 200Hz	17.64	12.70	12.70	12.60	6.91	19.01	13.59	4.312
phase-shifted 30Hz	17.96	12.33	10.82*	12.53	13.14	10.20	13.23	2.866
parallel 200Hz	9.55	8.14	11.83	17.19	5.12*	12.66	11.87	3.473
parallel 30Hz	9.97	2.83*	5.55*	16.68	4.50*	13.00	13.22	3.363

Table 2 The result of Visio-Tactile threshold (mm) adjusted by Abbott's formula. The values marked "*" are excluded in calculating mean and S.D..

subjects	A	B	C	D	E	F	mean	S.D.
fixed 200Hz	10.75	9.82	10.95	11.23	11.47	13.59	11.30	1.258
fixed 30Hz	10.23	10.33	9.41	12.68	9.59*	11.01	10.73	1.229
phase-shifted 200Hz	16.13	12.59	12.58	12.57	8.05	13.63	12.59	2.617
phase-shifted 30Hz	15.62	12.35	12.25*	12.53	12.98	11.39	12.97	1.587
parallel 200Hz	10.71	10.01	12.15	14.93	10.95*	12.60	12.08	1.908
parallel 30Hz	10.63	10.49*	10.30*	13.71	11.96*	12.89	12.41	1.594

is the ratio of answered "yes" of the fitted curve at 0mm. Pl is called lapse rate. Pl is that at 25mm. From Table 2, we can know VTT as psychological threshold. On the contrary, Table 1 shows specification for engineering use.

Tables show that the VTT is about 10 to 13 mm regardless of the stimulation patterns. However, the standard deviations and the means become larger if the stimulated points are moved. The selections of tactile receptors show no obvious difference in the mean. But, in the standard deviation, 30 Hz stimuli were smaller than 200Hz in the 3 tests. This result suggests that Meissner's corpuscle could detect the position difference more accurately.

5. CONCLUSION

In this paper, we proposed the concepts of Visio-Tactile Projector (VT Projector), and examined Visio-Tactile threshold (VTT) for design of VT Projector. By combining Airborne Ultrasound Tactile Display (AUTD) with image projector, we made the set up for measuring VTT in which subjects can see the stimulated points all the time while the examination.

We measured VTT by constant methods. VTT measured in this paper were in three movement patterns and two vibration patterns. The results showed that VTT is about 10 to 13mm regardless of stimulate patterns. In addition, the existence of movement tends to widen VTT and the frequency dependence of the results suggests that Meissner's corpuscle could detect the position difference more accurately.

VTT we tested were only 6 patterns. These 6 patterns include a variety of stimulation velocities or areas. The results didn't show obvious difference in VTT among these 6 patterns. In these test, we only applied one-point stimulation. One of our future works is examining VTT for multiple stimulation points.

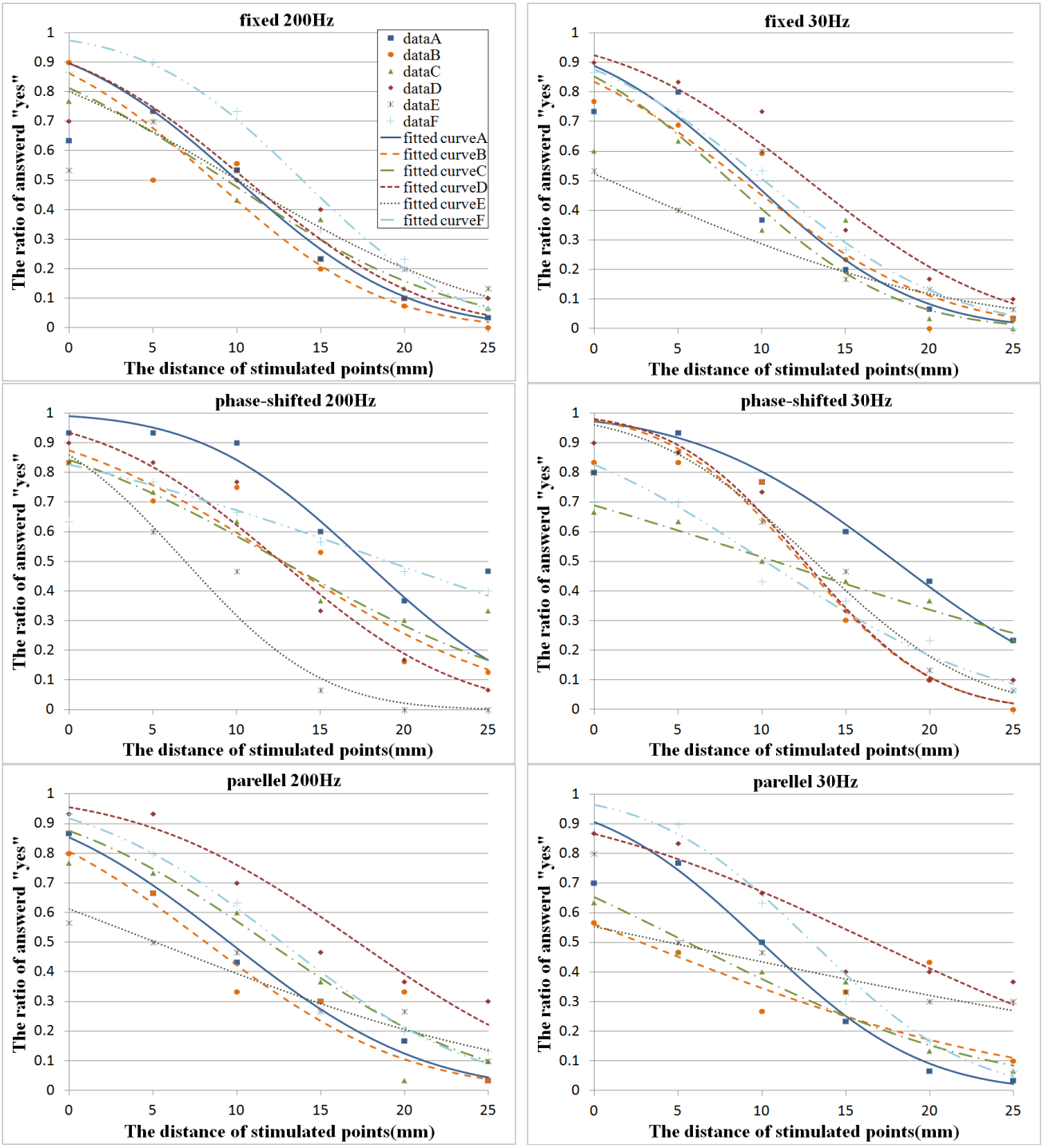

Fig. 5 The plots of experimental data and fitted curves. The 6 graphs share the legends of the first graph.

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