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Designing a Vibro-Tactile Wear for “Close Range” Interaction for VR-based Motion Training

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Abstract

This paper presents a vibro-tactile display system to increase the “presence” of the target interaction object and support human’s interaction with moving objects at a close range. Our particular interest is in applying it to VR based motion training in a system called the “Just Follow Me (JFM)”. JFM uses a metaphor called the “Ghosts”, which is a transparent rendering of the appropriately scaled trainer motion seen from the first person viewpoint. To aid the training process, we propose to use a vibro-tactile display on the whole or significant parts of the body. The tactile display can be used to direct the motion, indicating to which direction the limbs need to move, and how much. This paper describes the empirical findings for setting a guideline in designing a 3D vibro-tactile array display system. Through series of experiments, we try to find the appropriate resolution for the vibrator lay out, type of tactile stimuli, and stimulation rate.

Key words: virtual reality, tactile interface, vibrator, close range interaction, motion training

1. Introduction

Researches in 3D interaction researchers have identified and extensively studied the four “basic” or “universal” interaction tasks for 3D/VE applications, namely, navigation, selection, manipulation and system control [BOW99]. However, most interaction schemes that have been devised for these tasks are suitable for interacting with small (or large and distant), graspable and non-moving objects (for instance, everyday household objects, menu items, buttons, etc.). Another useful manner in which humans may interact with the world is interacting with relatively large and slowly moving objects (at close range) through his whole body. Examples in the real world may include interacting with other humans through direct contact (e.g. dancing, teaching or guiding motion, being in the crowd), and feeling the flow of the wind or fluid. The distinguishing characteristic of this type of interaction is the importance of haptic or tactile modality, in its own right and as an auxiliary information channel to the visual sense (as the human is usually “looking” at only part of his body or the incoming signal). However, tactile devices usually have very small display areas, targeted for use with the fingertips only, and are difficult to mount on haptic devices [ALL98][BUR96][MAS94]. As an alternative to such difficulties in using force feedback or high fidelity texture simulating tactile devices and to yet take advantage of the vast tactile sensors humans possess, several researchers have proposed the use of attaching vibratory tactile devices to parts of the human body [ERI02][HON97][JAN00]. These devices would directly convey certain information toward the whole (or at least significant portion of the) body by stimulating a relatively large area of the skin.

This paper presents a vibro-tactile display system to increase the “presence” of the target interaction object and support human’s interaction with moving objects at a close range. Our particular interest is in applying it to VR based motion training in a system called the “Just Follow Me (JFM)”[UNG02]. JFM uses a metaphor called the “Ghosts”, which is a transparent rendering of the appropriately scaled trainer motion seen from the first person viewpoint. As illustrated in Figure 1, the ghostly master, initially coincident with the trainee’s body, guides the motion, and this is seen, from the first person viewpoint of the trainee, as trainer’s limbs moving out of his body. The trainee is to follow by moving his own limbs to match the profiles of the trainers (i.e. ghost’s) motion.

To aid the training process, we propose to use a vibro-tactile display on the whole or significant part of the body. A tactile display is appropriate because of its wearability, mobility, and ability in stimulating the whole body, a characteristic that is required to support the effect of the Ghost metaphor. The tactile display, in addition to help recognizing the presence of the ghostly trainer immersed in the trainee’s body (and its moving in and out), can be further used to direct the motion, indicating to which direction the limbs need to move, and how much. Although the role of the tactile display would be auxiliary to that of the visual, there are situations in which trainees need to rely solely on the tactile display due to the narrow field of view (of the

HMD), inability to see (e.g. hands behind the back), and motion restriction (e.g. trainee must fixate on the golf ball).

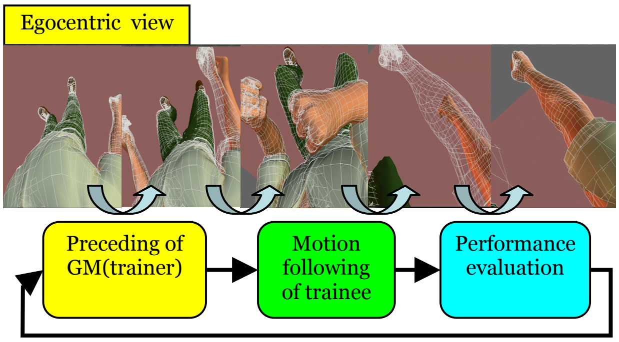

Figure 1: The Concept of the Ghost Metaphor for VR based motion training.

For this purpose, we have designed a tactile wear called the POS.T.Wear. Unfortunately, despite prior proposals [JAN00][HON97][TSAT], there is not yet a definite guideline to follow for how to design such a vibro-tactile device, nor are there sufficient past implementations upon which to base our design. Thus, the various system parameter values (such as the vibrator resolution, vibration rate, and type of tactile stimuli) of POS.T.Wear were determined based on, albeit very few, previously reported research results [JAN00][JAN02] and findings from a usability experiment we have conducted ourselves.

2. Related Work

Most researches on tactile feedback systems have focused on techniques to exactly recreate the texture of virtual surfaces using special devices and materials such as the piezo-electric elements [ALL98][WEL95]. These systems typically are applied to a relatively small skin area such as the fingertip. The proposal to use tactile feedback (usually using vibration) as an abstract information channel has been proposed in several application contexts also. Typically, to effectively convey certain information, such tactile feedback systems are applied to a larger skin area (e.g. abdominal region), thus are often in a wearable form. Acoustic based vibratory game chairs have already hit the commercial market [SOU]. NASA has developed a system called the TSAS (Tactile Situation Awareness System), a tactile vest to help pilot's situation awareness in aerial navigation and combat [JAN02][TATS]. Tan et al. have proposed a vibro-tactile chair that stimulates user's back to convey abstract information. Tan has reported on the effect of sensory saltation, a haptic spatio-temporal illusion that with appropriate spatial and timing parameters evoke a powerful perception of taction. This effect, for instance, can be taken advantage to design an economic tactile wear with minimum number of vibrators. E. Gunther's Skinscape is a vibro-tactile suite that covers the whole body and was used as a test platform for producing "pleasant" tactile compositions [ERI02]. Most of these work were rather concept presentations and reported less on design issues. The work of Erp et al[JAN02]. probably the first in-depth study on the design and ergonomic issues for vibro-tactile feedback systems. Their work reported on the results of the "two point localization" test in which an appropriate (with respect to the human's tactile capability) distance between vibrators was derived at about 4cm, and inter stimulus interval at about 200ms.

Figure 2: POS.T. Wear

3. POS.T.Wear

POS.T. Wear stands for POStech Tactile Wear, and for now, is an array of vibratory motors laid out in a cylindrical fashion to be worn on the torso region. The vibratory motor is shaped like a flat coin with the radius of about 7mm, and the thickness of about 3.5 mm (See Figure 2). It has a voltage range of 2.5 Volts to 3.8 Volts and can produce between 8,500 and 15,000 rpm. Currently, a total of 60 motors are used; there are five circular layers (or rings) in which 12 motors are spaced out at 30 degrees (See Figure 3). This initial spacing was chosen following the work of Erp (spacing of about 4cm) [JAN98], and it was also convenient to use the "12 clock hand" directions. The motors are attached to a tight fitting T-shirt (to make sure the motors are in contact with the body) using a pre-built calibration fixture as shown in Figure 2 (for each user). The motor array is wrapped around by a rubberband material to apply minimal pressure. The motors are controlled by a Pentium PC through a custom-built interfacing hardware. To be used for the VR based motion training system with the Ghost metaphor, it needs to be extended so that it can be worn on other parts of the body such as the arms and the legs.

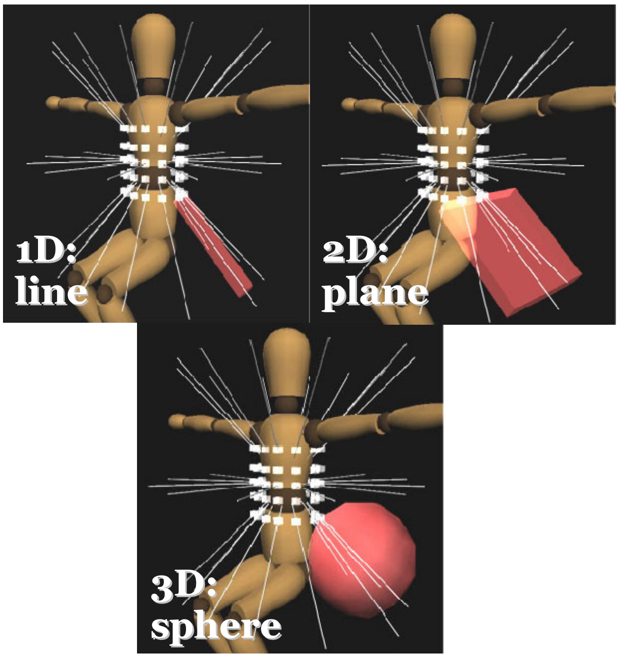

Figure 3: Three types of stimuli for specifying directions (or moving objects).

4. The Experiment

In order to further design POS.T. Wear so that it could be used effectively to guide or present 3D directions of closely moving objects (e.g. water flow, moving torso/arms/legs of the trainer ghost), we tested for three types of tactile stimuli, namely using a “moving” 1D line, 2D plane and 3D (volumetric) sphere (See Figure 3), and measured how accurate the user was able to understand the conveyed directional information. We also asked the users as how much presence one felt of the moving object and which type of a stimulus one preferred to use. The tactile feedback is produced by vibrating the motors in the intersected part between the moving object (line, plane or sphere) and the cylindrical motor array. For instance, as for the moving “line”, only one motor would vibrate as the line virtually starts to penetrate the body, then as it emanates out of the body, the second motor on the other end would start to vibrate. The directional cues were given with respect to an origin assumed to be located mid point between the belly button and the arm pit (See Figure 3).

4.1. Experimental Set up

The experimental set up is shown in Figure 4. After the user is fitted with the POS.T. Wear, one sits on a chair looking at a 61” rear projected display that shows the virtual environment that the user is situated in (the user is surrounded by a spherical grid). Upon a tactile stimulus, the user reports, mainly looking at the display, the direction using an arrow like stick equipped with the orientation tracker[1], which also appears in the virtual environment. The mock-up doll was used to rotate the virtual environment and be able to report directions that emanate behind one’s back.

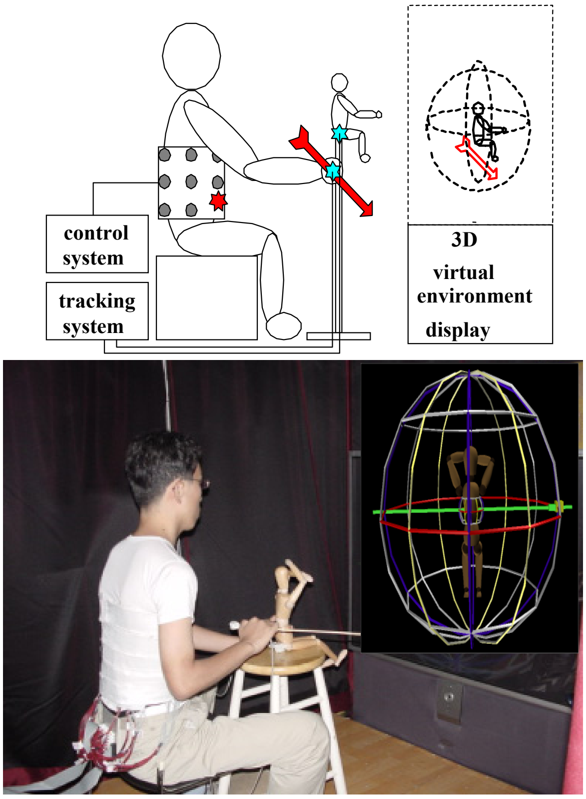

Figure 4: Experimental set up.

4.2. Experimental Design

As already mentioned three types of directional tactile stimuli were used, and we also tested them under two different speeds of the moving directional objects (fast: 700 ms and slow: 3500ms for the object to move from one end to the other). A Two Factor Within-Subject Design produced six experiment combinations as summarized in Table 1. Each of the twenty subjects tried out each combination in a random order and produced 120 data sets upon which ANOVA was carried out. All subjects were men of average age of 24, and average height of 173 cm.

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[1] www.polhemus.com: Polhemus Ultratrak Tracking System: update rate 120Hz.

Table 1. Six experiment combinations

Tactile Shape	3D	2D	1D
Slow Speed	36 trials	36 trials	36 trials
Fast Speed	36 trials	36 trials	36 trials

4.3 Task and Experimental Procedure

The subject was given 36 randomly generated directional feedbacks through the POS.T. Wear and reported the direction by moving the arrow stick and selecting a particular point on the spherical grid in the virtual environment shown in the display. A subjective questionnaire was filled out after all the combinations were tried out, and a final interview was conducted for any final thoughts from the subject.

It took about 1 hour for the subject to carry out the main tasks for the six experiment groups. Prior to carrying out the main task, the subjects spent an hour to prepare for the experiment, being fitted with the tactile wear, answering to personal questions (e.g. bio data, background, prior exposure to 3D environments, or vibratory devices, etc.), practicing the direction reporting interface, and getting familiar to the vibratory stimuli.

5. Results

5.1. Accuracy

Accuracy of the user responses was measured in two ways. First measure was the ratio between the correct and incorrect response (regardless of how much user's answer deviated from the right answer), and the second measured the normalized mean error angle of the user responses.

ANOVA has revealed that using the moving 1D line produced the least directional error compared to the moving 2D plane and 3D sphere. No statistical difference could be found between the 2D plane and 3D sphere (See Figure 5). More accurate reports of directions were observed for the slow moving directional cues (See Figure 6). Figure 10 shows that among the 12 directions around the ring, accuracy was significantly lower at the diagonal directions (namely, 1, 2, 4, 5, 7, 8, 10, 11 o'clock directions) than at the orthogonal directions (12, 3, 6, 9 o'clock directions). Three curves each represent accuracy data from the highest ring, the middle ring and the lowest ring. This result is also consistent with the findings of van Erp [JAN02]. This allows us to deduce that lowering the device resolution at 8 directions only would still produce a reasonable performance, and indeed, such an analysis with respect to the 8 directions (e.g. data from 11 and 10 o'clock directions merged) would produce about 10 % increase in accuracy.

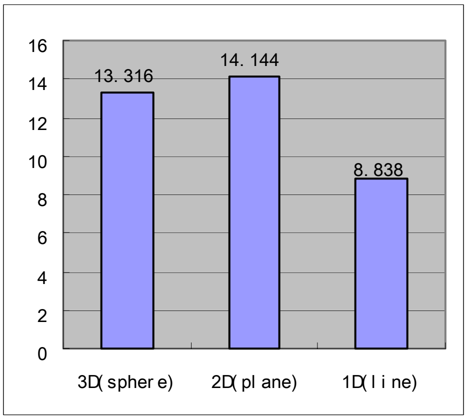

Figure 5: Normalized mean error angle vs. three types of directional stimuli.

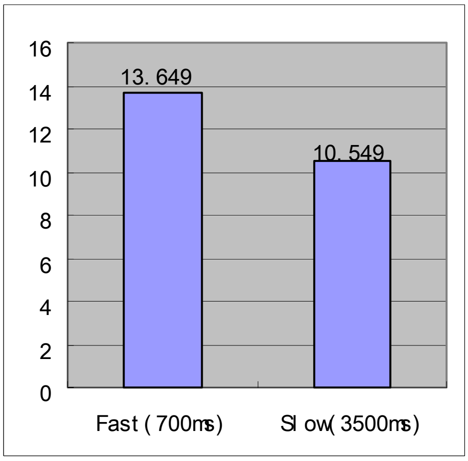

Figure 6: Average mean error angle and object moving speeds.

5.2 Subjective Evaluation

Aside from the objective accuracy measure, users were polled about how they felt about the different styles of tactile feedback. First, as for how much the users thought the given tactile was effective in conveying directional information, the result was similar to the objective evaluation, that is, users also felt the tactile stimulus of slow moving 1D line was the best way (among the three) to convey directional information (See Figures 7, 8, and 9).

Table 2 shows the user's preference for the stimulus style when asked for feeling the presence of the interaction object. Interestingly, in this case, users preferred the slow moving 3D spheres over others. The fast moving 3D spheres was preferred almost as much as the slow moving 1D lines. This tells us when the moving object was too fast, the users were not able to feel its presence nor fully recognize its moving direction.

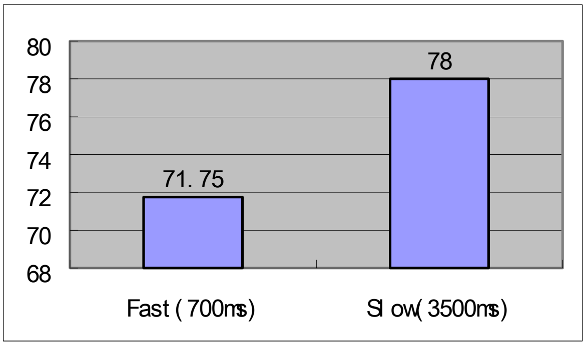

Figure 7: Average score (out of 100) given to particular stimulus speed.

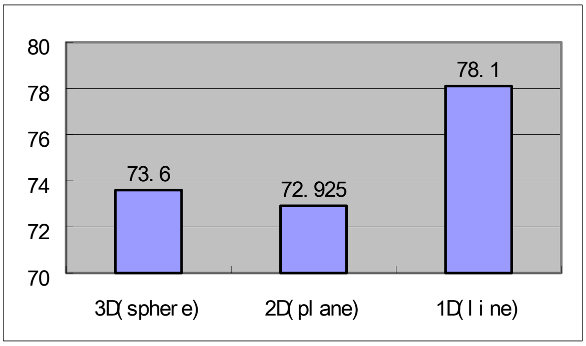

Figure 8: Average score (out of 100) given to particular stimulus shape.

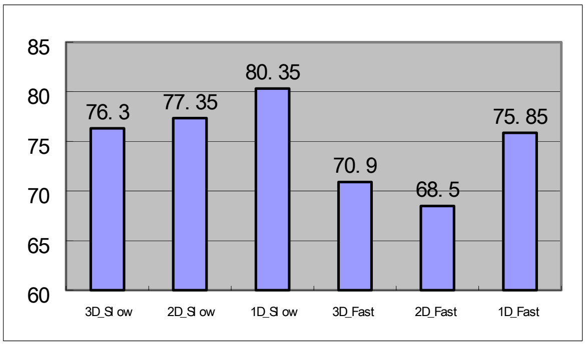

Figure 9: Average score given to the 6 tactile patterns (shape-speed).

Table 2. Mean Preference Level for Presence (Lower value means higher presence)

	Virtual object collision feeling	σ
3D_Slow	**2.6**	1.845
2D_Slow	3.6	1.698
1D_Slow	3.65	1.663
3D_Fast	3.35	1.755
2D_Fast	**4.35**	1.663
1D_Fast	3.45	1.356

The experimental findings can be summarized as follows:

- Providing tactile feedback in terms of a moving 1D line produced the best results in terms of guiding or presenting 3D directional information accurately.
- The accuracy dropped significantly at the diagonal region around the abdomen, and at least for this region, relatively less vibrators may be placed (e.g. only 8 around the ring) to achieve results that would be obtained when having 12 or more vibrators.
- In terms of feeling the presence of the interaction object, providing tactile feedback in terms of a volumetric shape was better.

From these findings, as for using POS.T. Wear for the proposed VR based motion training system, we suggest to use the moving 3D volumetric tactile feedback when the user is able to see the trainer's ghostly limb (tactile feedback is used as auxiliary to visual), and use the moving 1D line when the trainer's ghostly limb can not be seen (e.g. when holding a golf club behind one's head).

6. Conclusion and Future Work

This paper presented a design of a vibro-tactile feedback system called the POS.T. Wear. While the basic system parameters were determined from past research results, additional design was made through a usability experiment that considered different styles of tactile feedback for the best way to convey directional information to the user. Experiment results tell us that the tactile feedback system should be designed differently depending on which aspect was more important: information accuracy or presence of the interaction object.

7. Acknowledgement

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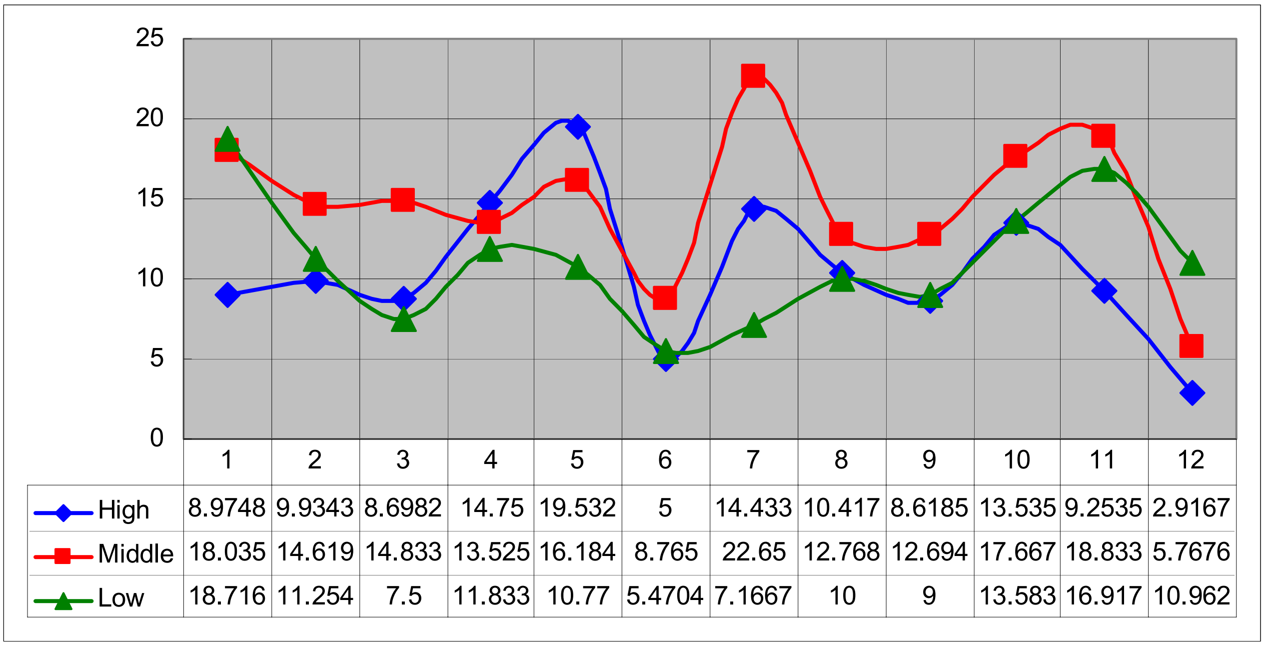
Figure 12: Avg. dist. error and Direction



	1	2	3	4	5	6	7	8	9	10	11	12
◆ High	8.9748	9.9343	8.6982	14.75	19.532	5	14.433	10.417	8.6185	13.535	9.2535	2.9167
■ Middle	18.035	14.619	14.833	13.525	16.184	8.765	22.65	12.768	12.694	17.667	18.833	5.7676
▲ Low	18.716	11.254	7.5	11.833	10.77	5.4704	7.1667	10	9	13.583	16.917	10.962