Evaluating Haptic Feedback in Virtual Environments using ISO 9241-9

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ABSTRACT

The ISO 9241 Part 9 standard [2] pointing task is used to evaluate passive haptic feedback in target selection in a virtual environment (VE). Participants performed a tapping task using a tracked stylus in a CAVE both with, and without passive haptic feedback provided by a plastic panel co-located with the targets. Pointing *throughput* (but not speed nor accuracy alone) was significantly higher with haptic feedback than without it, confirming previous results using an alternative experimental paradigm.

KEYWORDS: pointing in 3D, haptic feedback, Fitts' law

INDEX TERMS: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems – virtual reality.

1 INTRODUCTION

Many VEs require efficient reach or touch-based input techniques. This is challenging due to input restrictions and practical requirements of existing VR systems. VR input devices are generally either of handheld or wearable size which limits the number of controls. Consequently, VR systems often use 3D trackers as input devices, allowing direct input by moving one's tracked hands in space. Direct manipulation interfaces based on this approach allow users to reach for and grab virtual objects. It can be difficult to track hands and fingers accurately and virtual objects do not afford haptic feedback.

Previous research has demonstrated that haptic feedback is beneficial [7, 8] and even a flat surface co-located with the virtual objects can help improve user performance. Our study compared target selection with and without passive haptic feedback provided by a plastic panel. The study used a standardized task based on Fitts' law, a predictive model of rapid aimed movement. The task involves tapping between targets of known sizes and distances. The ISO 9241-9 standard [2] prescribes a method to allow easy (and direct) comparison between results of different experiments.

2 BACKGROUND

Similar to the presence of a supporting surface in traditional mouse-based input, it is generally accepted that passive haptic feedback aids users of virtual environments [3, 4, 5]. Thus researchers have added small physical support surfaces to traditional VR systems to emulate the surface the mouse operates on. Notable among these are the HARP system [4, 5], the Virtual Notepad [8], and the Personal Interaction Panel [9].

Other work has compared 3D interaction on and off tabletop surfaces to assess the importance of passive haptic feedback in a display-input coupled environment. For example, it was found that object positioning was faster due to the support offered by the tabletop surface, but accuracy was slightly worse [10].

While multiple studies confirm that haptic feedback is beneficial, given the various protocols used it can be difficult to generalize these results to different tasks, or to quantify the general benefit of haptic feedback in VR. Fitts' law is a well established model of pointing performance [1] and can provide solutions to some of these problems. It has not yet been used to evaluate haptic feedback in generic 3D pointing tasks. Here we use Fitts' Law to evaluate haptic feedback in VEs using ISO 9241-9 standard.

2.1 Fitts' Law

Fitts' law [1] is an empirical model of rapid aimed movements:

$$MT = a + b \cdot \log_2\left(\frac{A}{W} + 1\right) \tag{1}$$

MT is movement time, *A* is the amplitude of (distance to) the target, and *W* is the target width. The log term is Index of Difficulty (*ID*), measured in bits. The coefficients *a* and *b* are found via linear regression. Fitts' law predicts movement time with great precision once these coefficients are known for a given interaction style/device [6]. Equation (1) indicates that smaller, farther targets are harder to hit than nearby, larger targets. Note that *ID* captures the overall difficulty of a movement task based on the individual parameters.

The use of Fitts' Law to evaluate pointing tasks has been standardized via ISO 9241-9, which describes a task (Figure 1) for evaluating pointing devices [2]. This standard prescribes how to compute effective width and distance, and ultimately *throughput* of a pointing device. Effective width (W_e) is 4.133 standard deviations of the over/undershoots to the target, as projected onto a line between the source and the target. This corresponds to performing the pointing task with 96% accuracy (i.e., a 4% miss rate) [2]. Effective amplitude (A_e) is the average length of these projected motions. Throughput is thus:

$$TP = \frac{\log_2\left(\frac{A_e}{4.133 \times W_e} + 1\right)}{MT} \tag{2}$$

and is measured in bits per second [2]. This measure aggregates pointing speed and accuracy into a single score, and is unaffected by speed-accuracy tradeoffs [7]. It is commonly used as a primary characteristic of pointing devices and allows direct comparison between devices evaluated using the standard method.

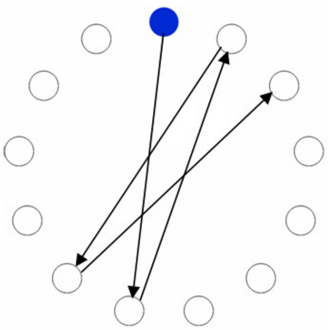

Figure 1. Circular target arrangement, per ISO 9241-9. Arrows depict the ordering of the first five targets in the sequence.

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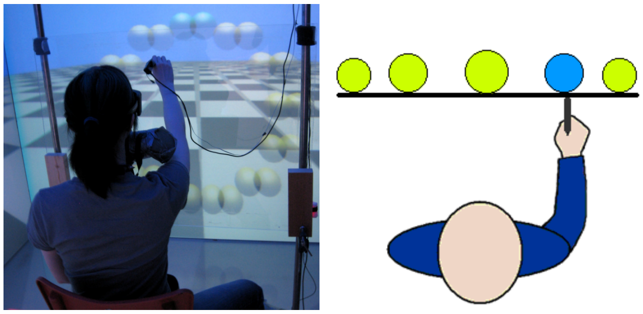

Figure 2. (Left) Participant performing the pointing task in the CAVE, with the plastic panel in place. (Right) Relative positions of the participant, plastic panel, and the targets.

3 EXPERIMENT

Twelve participants (seven male, aged 21 to 29) took part in the study. All had stereo viewing capability and were right-handed.

The study was performed in a six-sided CAVE. A chin rest was used to immobilize the head. A single-button stylus was used as the input device and tracked by an IS-900 tracker. A transparent plastic panel (~1 m x 0.5 m) provided haptic feedback. This panel was positioned in front of the chair, and between the participant and the front wall of the CAVE. The panel was physically removed from the stand for the condition without haptic feedback. The relative positions of the experiment apparatus and participant is shown in Figure 2.

The software displayed a simple virtual environment, consisting of a white/grey tiled floor, and thirteen targets floating in front of the user, Figure 2 (left). A virtual pen-tip visually appeared to be registered at the physical tip of the stylus. Thirteen spherical targets were arranged on a vertical plane a distance of 0.3 m in front of the observer (stereoscopically projected 0.7 m from the CAVE wall). Targets were arranged in circles of varying diameters centered in front of the head. Targets were positioned at regular intervals along the perimeter of the circle, as prescribed by the ISO 9241-9 task [2] (Figure 1). Upon clicking the stylus button, the current trial would end, and the next target would activate. Clicking while intersecting the indicated target with the stylus tip was counted as a "hit". Missed targets would highlight red for the remainder of the target circle. Hit targets returned to the original yellow colour instead. This provided participants with immediate and lasting feedback regarding their performance. The size of targets, and distance between targets was varied to provide a range of pointing task difficulty, for a total of nine distinct *ID*s.

Participants were instructed to click the blue highlighted target as quickly and as accurately as possible. The software logged the time between clicks and whether a click hit the current target.

The experiment employed a $2 \times 3 \times 3 \times 3$ within-subjects design. The independent variables were haptic feedback (present or absent), target size (2.8 cm, 4.0 cm, and 5.2 cm diameter spheres), distance between targets (circle of diameter 22 cm, 27 cm, and 32 cm), and block (1 to 3). The nine combinations of target size and distance comprised 9 indices of difficulty, computed using Equation (1). Since there were 12 clicks recorded per circle (the first was not counted), each participant performed a total of 648 trials. Hence, over 12 participants, 7776 trials were recorded. The dependent variables were movement time (ms), error rate (expressed as a percentage), and throughput (bps).

4 RESULTS

Although throughput combines speed and accuracy, we first examine these separately. The average movement time was 1.60 s (*SD* 1.17) without haptics and 1.59 s (*SD* 0.99) with haptic feedback. The difference was not significant ($F_{1,11} = 0.04$, ns).

A selection error occurs when selection is made outside the volume of the target sphere. The average error rate without haptics was 13.3% (*SD* 7%). With haptics, it was 11.1% (*SD* 6%). Though fewer errors occurred in the presence of the plastic panel, the difference between error rates was not significant ($F_{1,11} = 0.69$, ns). Motion trail analysis suggested a greater number of overshoots in the depth direction without haptic feedback.

Although the differences between movement times and error rates were not significant, throughput, which combines both, was significantly different ($F_{1,11} = 6.47$, $p < .05$). The throughput for the no haptic feedback condition was 2.37 bps (*SD* 0.74). For the haptic feedback condition it was 2.56 bps (*SD* 0.76).

Given the relatively low throughput (mouse throughput is around 4.5 bps) we speculate that 3D pointing will not reach the performance levels attainable in 2D pointing tasks. This may be due to jitter and lag (which are orders of magnitude lower with a mouse), and user fatigue often caused by 3D devices. As a consequence, 3D selection still has room for improvement. However, adding even simple haptic feedback is a step in the right direction.

5 CONCLUSIONS

We conducted an ISO 9241-9 based study of 3D pointing in a CAVE. Specifically, we attempted to detect differences in pointing throughput due to the presence of haptic feedback.

Results of our study indicate that passive haptic feedback significantly improved pointing throughput, but not speed or error rate. These results are consistent with previous findings, though perhaps understated due to tracking issues during the study. We argue for the use of throughput as a measure, both because of the standardized experimental paradigm, and because it appears to elicit greater differences between conditions. This is likely because it incorporates both speed and accuracy.

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