Target Pointing in 3D User Interfaces

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ABSTRACT

We present two studies using ISO 9241-9 to evaluate target pointing in two different 3D user interfaces. The first study was conducted in a CAVE, and used the standard tapping task to evaluate passive haptic feedback. Passive feedback increased *throughput* significantly, but not speed or accuracy alone. The second experiment used a fish tank VR system, and compared tapping targets presented at varying heights stereoscopically displayed at or above the surface of a horizontal screen. The results indicate that targets presented closer to the physical display surface are generally easier to hit than those displayed farther away from the screen.

KEYWORDS: Target selection, pointing, tapping, virtual reality.

INDEX TERMS: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems – virtual reality. H.5.2: User Interfaces – input devices, interaction styles.

1 INTRODUCTION

Target pointing is a fundamental task in computer interfaces, and is a basis for direct manipulation interfaces. The WIMP interface paradigm (Windows, Icons, Menus and Pointing device) is a good example, as virtually all operations are accessible by pointing the cursor at interface widgets. Pointing in 2D interfaces has received a great deal of attention and is well modeled by Fitts' law [4].

Pointing is also required in 3D direct manipulation interfaces, but elementary 3D pointing tasks have not received the same attention. Few attempts have been made to model 3D pointing tasks. Most research in virtual object selection and manipulation instead focuses on high-level techniques. Experimental designs vary between studies, thus it is difficult to generalize findings.

The ISO 9241 standard part 9 [6] describes a method for evaluating pointing devices. It is based on Fitts' law and ultimately computes throughput, which represents information capacity (in bits per second), which enables direct comparison between devices. We propose using this standard for 3D pointing, too. There have been few, if any, previous attempts to employ this methodology in evaluating 3D input devices. We examine some of the issues in extending the standard for use in 3D user interfaces in the context of the two experiments described below.

2 TARGET POINTING

The VR community has studied target pointing, i.e., object selection, extensively [1-3, 5, 7, 9]. Yet, elementary pointing tasks have not been formalized or modeled as well as in the 2D user interface domain. Most VR object selection techniques are based on either ray casting or virtual hand metaphors. Ray-based techniques cast a virtual ray into the scene from the user's hand, finger, or cursor and selects objects hit by this ray. The virtual hand metaphor requires users to intersect their hand representation with objects. Both paradigms use rapid aimed movement, as modeled by Fitts' law [4]:

$$MT = a + b \cdot ID, \quad \text{where } ID = \log_2\left(\frac{A}{W}+1\right) \qquad (1)$$

MT is the movement time, and *a* and *b* are determined via linear regression for a given technique. *ID* is the index of difficulty (in bits). *A* is the movement distance, and *W* is the target width. *ID* represents the task difficulty based on the target size and distance. Hence, small, far targets are harder to hit than large, near targets.

ISO 9241-9 employs a standardized pointing task (Figure 1) based on Fitts' law [6]. The standard uses throughput (*TP*) as a primary characteristic of pointing devices [6], which is given in bits per second as:

$$TP = \frac{ID_e}{MT}, \quad \text{where } ID_e = \frac{A_e}{W_e} \qquad (2)$$

where ID_e is the *effective* index of difficulty, and *MT* is the measured average movement time for a given condition. ID_e uses *effective* scores to account for the tasks users really performed, as opposed to presented task. Effective width is defined as:

$$W_e = 4.133 \cdot SD_x \qquad (3)$$

where SD_x is the standard deviation of the over/under-shoot projected on to the task axis (line between targets) for a given condition and A_e is the averaged actual movement distance.

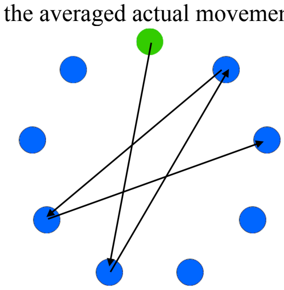

Figure 1. ISO 9241-9 reciprocal tapping task with nine targets. Arrows depict target order.

Throughput incorporates both speed and accuracy and is unaffected by speed-accuracy trade-offs [8]. It may also account for device noise common to 3D tracking technology [9].

3 PASSIVE HAPTIC FEEDBACK STUDY

It is generally accepted that haptic feedback improves the usability of immersive virtual environments. The goal of this study was to determine if throughput would elicit this effect in a 3D pointing task based on to the ISO 9241-9 task.

Twelve participants took part in the study. The study was conducted in a 6-sided CAVE, using an Intersense IS-900 tracked stylus as the input device. Participants' heads were positioned on a headrest to ensure consistency. Thirteen spherical targets were stereoscopically presented 0.3 m in front of the participants, arranged in a vertically oriented circle. Passive haptic feedback was provided by co-locating a transparent plastic panel with the targets. The target positions conformed to the ISO task (Figure 1). Participants were instructed to click the highlighted target as quickly and accurately as possible. Figure 2 depicts the setup.

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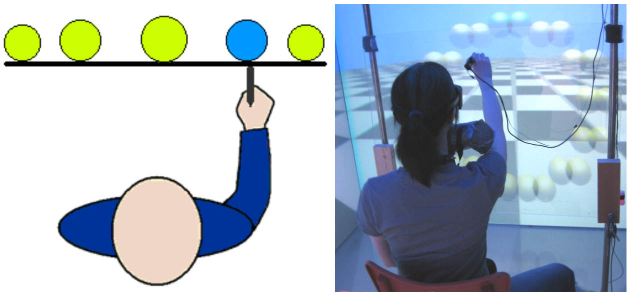

Figure 2. (Left) The pointing task, from above. (Right) Participant performing the task in the CAVE.

The experiment employed a 2 × 3 × 3 × 3 within-subjects design. The independent variables were haptic feedback (present or absent), target size (sphere diameter 2.8 cm, 4.0 cm, and 5.2 cm), distance between targets (circle diameter 22 cm, 27 cm, and 32 cm), and block (1 to 3). The dependent variables were movement time (ms), error rate (percent), and throughput (bps). Results were analyzed with repeated measures ANOVA.

The average movement time was 1.60 s (*SD* 1.17) without haptic feedback and 1.59 s (*SD* 0.99) with haptic feedback. The difference was not significant ($F_{1,11} = 0.04$, ns). The average error rate without haptic feedback was 13.3% (*SD* 7%). With haptic feedback, it was 11.1% (*SD* 6%). This difference was also not significant ($F_{1,11} = 0.69$, ns). However, throughput, which incorporates both speed and accuracy, was significantly different between conditions ($F_{1,11} = 6.47$, $p < .05$). The throughput without haptic feedback was 2.37 bps (*SD* 0.74), and haptic feedback increased it to 2.56 bps (*SD* 0.76).

4 Fish Tank VR Study

VR systems often use stereo graphics to project targets in front of, or behind, the display surface [1-3, 7]. Unlike volumetric displays [5], these displays introduce conflicts between the vergence and accommodation depth cues. The goal of this study was to evaluate the effect of these conflicts with the ISO 9241-9 task and also to compare the standard 2D tapping task with pointing in 3D space.

Twelve paid participants took part in the study. All had normal or corrected vision, and could perceive stereo depth. The study used a fish tank VR system consisting of a CRT monitor positioned horizontally, and a stylus tracked by a NaturalPoint *OptiTrack* tracker. The participants' heads were tracked using the same system, and the virtual camera position was coupled to the head position. Targets were stereoscopically presented either at the surface of the screen, i.e., without disparity, or at varying heights above the screen surface. Target height did not vary within a set of targets. Targets were on top of cylinders and textures were used to enhance depth perception. Participants were asked to click the highlighted target disk as quickly and accurately as possible. Figure 3 depicts the task and setup.

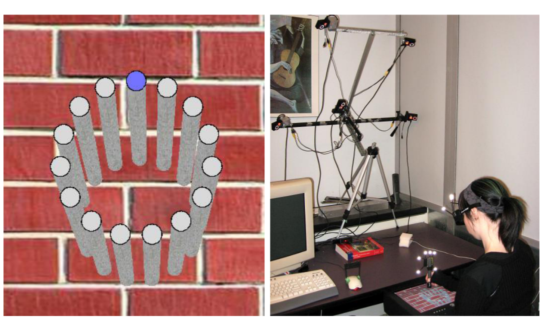

Figure 3. (Left) The pointing task, as viewed by the participant. (Right) Participant performing the task.

The grand mean movement time was 1053 ms. There was a significant main effect for target height ($F_{3,11} = 7.34$, $p < .001$) and block number ($F_{3,11} = 24.8$, $p < .0001$) on movement time. Higher targets took longer to hit than those at or near the screen. The overall error rate was 14.3%. There was no significant difference in error rate for repetition ($F_{3,11} = 0.90$, ns), or target height ($F_{3,11} = 0.14$, ns). The mean throughput was 4.77 bps. There was a significant main effect for target height ($F_{3,11} = 8.17$, $p < .0005$) and block ($F_{2,11} = 48.13$, $p < .0001$) on throughput. Linear regression of *MT* on *ID* indicates that Fitts' law best modeled movements at the surface of the screen ($R^2 = 0.88$), possibly due to the presence of haptic feedback there. Conversely, the 5 cm height was worst modeled by Fitts' law ($R^2 = 0.75$).

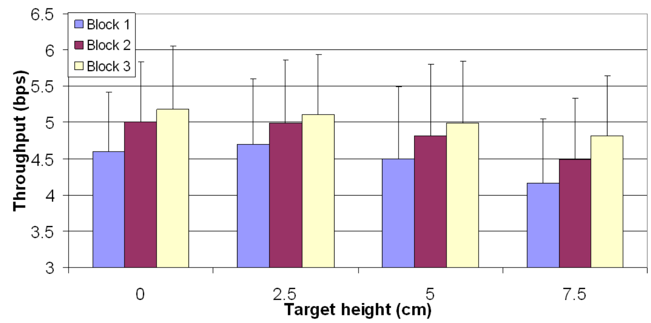

Figure 4. Throughput by target height and block.

5 Conclusion

We presented two studies evaluating 3D motions using variations on the ISO 9241-9 standard pointing task. The results of the first study indicate that passive haptics significantly improved pointing throughput. Throughput also helped elicit differences between conditions that were not detectable with standard speed or accuracy measures. The results of the second study indicate that pointing at targets presented stereoscopically above a display surface tends to be harder than pointing at targets presented near or at that surface. Increasing target height also degraded the correlation between movement time and task difficulty in Fitts' tapping tasks.

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