Effects of Latency and Spatial Jitter on 2D and 3D Pointing

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ABSTRACT

We investigate the effects of input device latency and spatial jitter on 2D pointing tasks and a 3D movement. First, we characterize jitter and latency in a 3D tracking device and an optical mouse used for baseline comparison. We present an experiment based on ISO 9241-9, which measures performance of pointing devices. We added latency and jitter to the mouse and compared it to a 3D tracker. Results indicate that latency has a stronger effect on performance than small spatial jitter. A second experiment found that erratic jitter "spikes" can affect 3D movement performance.

KEYWORDS: Latency, jitter, Fitts' Law, 3D manipulation.

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

1 INTRODUCTION

Three-dimensional input devices may allow transfer of real-world skills to VR. However, compared to a mouse, they suffer from high tracking noise, hand tremor and latency.

We investigated the effects of latency and jitter on pointing performance with 3D input devices. Our first study employed the ISO 9241-9 standard, a framework to evaluate pointing device performance. This study compares 2D pointing tasks using both a 3D tracker and mouse under several latency/jitter combinations. The mouse is used as a low-latency, low-jitter baseline condition. For comparison, we artificially added latency and jitter to match the tracker. We compared motions captured by the mouse optical sensor to those of a 3D tracking system tracking the mouse. The goal was to determine the effects of latency and jitter and to quantify their effects on device performance. A second study extended this into 3D movement performance.

1.1 3D Manipulation, Tracking, Lag and Jitter

VR systems often use 3D input devices, such as a 3D tracker, for a 6-DOF manipulation. These often suffer from latency and jitter. Foxlin provides an overview of tracking technologies [3].

Latency is the delay in response of a device to the position changes [3], and has been shown to impact performance in 2D and 3D tasks, [5, 9]. Spatial jitter, from both input device noise and hand tremor, may also affect performance. Designers may smooth noisy input, but this increases latency. Before making this trade, one must understand, which has a greater impact on performance.

A mouse can manipulate a 3D object indirectly via "handles" [2] that decompose manipulation into multiple sub-tasks along axes or planes. Other techniques, using constraint systems and ray casting [1], afford 3DOF manipulation with 2DOF devices. Users effectively click and drag objects in the scene, while software computes their 3D position by checking for collisions with other objects [7]. Studies comparing mouse-based and tracker-based 3D movement techniques found that the mouse performs better [8]. The authors speculated that differences in latency and/or jitter between the mouse and tracker might explain the differences.

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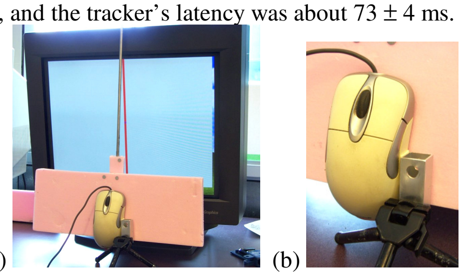
2 CHARACTERIZING SYSTEM LATENCY AND JITTER

A variation on Mine's method [6] was used to measure the latency of a USB optical mouse and a NaturalPoint *OptiTrack* 3D tracker (www.naturalpoint.com/optitrack). A tracked pendulum was suspended in front of the display (Figure 1a). The tripod-affixed mouse was placed 0.5 mm away from the pendulum surface. Software drew two lines; their endpoints moved in response to pendulum motion detected by their respective device. Video analysis revealed the average latency of the mouse was about 35 ± 2 ms, and the tracker's latency was about 73 ± 4 ms.



(a) (b)

Figure 1. (a) Pendulum setup in front of display. (b) Mouse affixed to tripod used in mouse latency measure.

Tracker jitter was measured with a tracked object on a turntable. The RMS value of the tracker jitter was about 0.3 mm.

3 EXPERIMENT 1 (2D POINTING)

This experiment used the ISO 9241-9 standard to compare devices. Fourteen participants took part in the study. A tracked mouse was used in all conditions. Some conditions used the mouse optical sensor. Others used the NaturalPoint *OptiTrack* tracker to detect the movement of the same mouse.

The software used a 2D task, derived from the Fitts' law, described in ISO 9241-9 [4]. The software presented 13 round targets arranged in a circle. Participants would click the targets as they were highlighted on the opposite sides of the circle. The software logged movement distance, time and errors. It also computed effective width as described in ISO 9241-9 [4].

Table 1. Input modalities used in study.

Modality	M	ML	MJ	M225	MT	TR	TA
Latency (ms)	35	75	35	225	75	75	75
Jitter (mm)	–	–	0.3	–	0.3	0.3	0.3
Movement	Rel.	Rel.	Rel.	Rel.	Rel.	Rel.	Abs.

The experiment had one independent variable, input modality, with seven levels. These are summarized in Table 1. Five of these used the mouse, and two used the tracking system. The mouse-based input modalities (start with "M" in Table 1) involved artificially adding latency and/or spatial jitter. The two tracker modalities were tracker with relative movement (as a mouse), TR, and tracker with absolute movement (tracked in the air), TA. The input modality ordering was counterbalanced with a Latin square.

Three target distances (320, 450 and 640 pixels) and three target widths (12, 25 and 64 pixels) were used, giving nine ID-s (*indices of difficulty*). They were randomly ordered (without replacement) in each of two blocks. The design of the experiment was 7 input modalities × 9 × 2 blocks, for a total of 126 rounds for each participant. The dependent variable was device *throughput* (in bits per second), calculated as described in ISO 9241-9 [4].

3.1 Results & Discussion

Results were analyzed with ANOVA. Input modality had a significant effect on throughput, ($F_{6,84} = 38.8$, $p < .0001$). Figure 2 shows the throughput of all input modalities, and is ordered to highlight groupings found with Tukey-Kramer post-hoc analysis.

The grand mean error rate was about 6 pixels. A latency of 40 ms reduced performance by about 15%. The 225 ms latency condition was worst, with about 50% the throughput of the baseline mouse. Spatial jitter did not significantly affect throughput. The MJ condition, with extra jitter, but no extra latency, was not significantly worse than the mouse modality, but was significantly better than both the ML and MT modalities, which had 40 ms of extra latency.

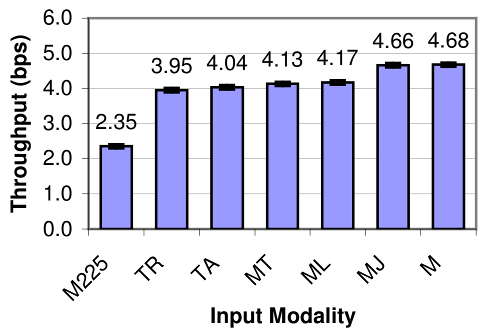


Figure 2. Throughput for all conditions. Higher throughput is better. Error bars represent ±1 std. err. Bars ordered to highlight groups.

4 Experiment 2 (3D Movement)

The second experiment examined 3D object movement. Twelve people participated in the study. The same tracked mouse was used in this experiment. The software used a ray-casting based 3D movement technique that requires only 2DOF from the input device. Depth is handled automatically by sliding objects on the closest surface behind their projection as they are moved [7].

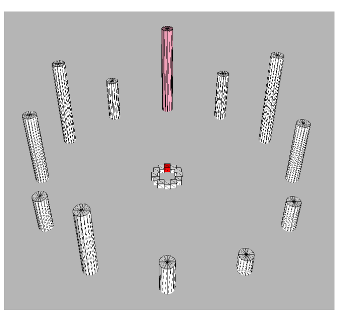


Figure 3. Experiment #2 task. Each cube was moved to the corresponding pillar, starting with the cube at the "noon" position.

The task was to move twelve unit cubes from the centre of a plane to corresponding pillars of varying height on a 20-unit radius circle. This was intended to simulate the ISO 9241-9 task used in the first study in a 3D scene with a fixed viewpoint.

This study had one independent variable, input modality, with four levels. The M, ML, MT and TA conditions from the first study were re-used. We used 10 blocks in this study; thus, the design of the experiment was 4×10.

The dependent variables were object movement time (in ms) and error. Error was recorded for both screen coordinates and 3D distance (in pixels or 3D units away from ideal position).

4.1 Results & Discussion

Results were analyzed with ANOVA. Input modality had a significant effect on object movement time ($F_{3,11} = 40.4$, $p < .001$). Tukey-Kramer analysis revealed no significant difference between any of the mouse modalities (M, ML and MT in Figure 4). However, the TA condition was about 30% slower than any mouse modality. This is likely due to jitter "spikes" in about 1% of the tracker samples, not present in the mouse. Spikes have a higher cost in 3D than in 2D, as they can result in objects "falling off" a pillar, prompting lengthy corrections. Object motion paths and error rate analyses supports this.

No significant difference was found in either 2D error ($F_{3,11} = 0.56$, ns) or 3D error ($F_{3,11} = 0.96$, ns). The grand mean 2D error was 7.2 pixels; in 3D it was 0.44 units, i.e., about half a cube width. Participants spent more time correcting the errors.

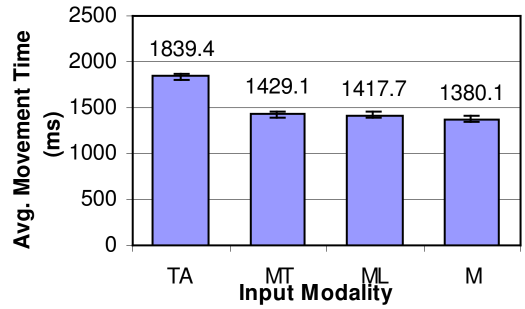


Figure 4. Average movement time, with standard error bars. Note this graph cannot be directly compared to Figure 2.

5 Conclusions

Latency had a stronger effect on performance in pointing tasks than low levels of jitter. The second study suggests that erratic jitter has significant performance costs as well. Future work will systematically vary both latency and jitter.

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