The Effect of Rotational Jitter on 3D Pointing Tasks

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ABSTRACT

Even when in a static position, data acquired from 6 Degrees of Freedom (DoF) trackers is affected by noise, which is typically called jitter. In this study, we analyzed the effects of 3D rotational jitter on Virtual Reality (VR) controllers in a 3D Fitts' law experiment, which explored how such jitter affects user performance. Eight subjects performed a Fitts' law experiment with or without additional jitter on the cursor. Results show that while error rate significantly increased above $\pm 0.5^{\circ}$ jitter and subjects' effective throughput started to decrease significantly above $\pm 1^{\circ}$ jitter, there was no significant effect on users' movement time. Further, the Fitts's law movement time model was affected when $\pm 2^{\circ}$ jitter was applied to the tracker. According to these results, $\pm 0.5^{\circ}$ jitter on the controller does not significantly affect user performance for the tasks explored here. The results of our study can guide the design of 3D controller and tracking systems for 3D user interfaces.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; *Pointing devices*; *HCI theory, concepts and models*.

KEYWORDS

Fitts' law; 3D pointing; controller; 3D Jitters; user performance

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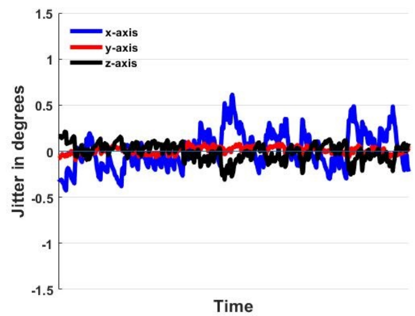

Figure 1: Rotational jitter signal recorded from a static, immobilized VR controller. Average absolute jitter was 0.15°, 0.03° and 0.07° for x, y and z axes, respectively. We observed maximum deviation on the x-axis with 0.614°

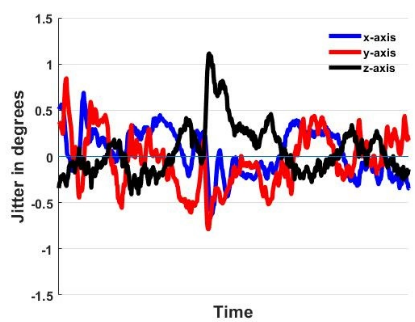

Figure 2: Rotational jitter signal recorded from a VR controller while a participant holds the controller in mid-air.Average absolute jitter was 0.21°, 0.24° and 0.21° for x, y and z axes, respectively. We observed maximum deviation on the z-axis with 1.114°

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INTRODUCTION

Immersive tracking systems rely on various sensors to detect user position or input, including inertial measurement units, infrared light, and multiple cameras. Many current virtual reality (VR) systems use inertial measurement units and infrared trackers to find the position of the head-mounted display (HMD) unit and hand-held controllers in 3D space. The raw data acquired from these sensors is not suitable for end-user applications due to measurement errors. To reduce the effects of such measurement errors, the data has to be processed by signal processing methods, depending on the device design and used sensors. Even after such signal processing, the data contains noise and this noise can be observed when the system is compared to a physical reference (Figure 1).

In addition to measurement noise, systems can suffer from temporarily unstable output due to artifacts from the used signal processing methods. Such instabilities can, e.g., instantly rotate (or re-position) the virtual object.

Apart from jitter introduced by the software and hardware, VR trackers are also affected by natural user behaviors, including hand tremor, breathing and the associated body sway, task errors and fatigue (Figure 2). All of these different errors and noises increase the jitter on the controller, and users have to adapt their movements to accurately position the cursor during a 3D pointing task.

In this study, we investigate how user performance is affected by different levels of rotational jitter during a 3D pointing task in a virtual environment (VE). Towards this goal, we add synthetic jitter to a virtual cursor and asked participants to perform a Fitts' law experiment with three different jitter levels. We compared their results to the baseline without additional jitter.

RELATED WORK

3D Pointing and Controllers

There are different techniques to select and manipulate objects in VR. Ray-casting is the most commonly used technique for distant object interactions in VE. Many VR application designers adopt the ray-casting technique for 6DoF controllers [3] for effective and agile interaction.

Jitter During Task Execution

Jitter can be defined as small fluctuations on the signal, e.g., [7]. In VE, jitter causes small positional and rotational changes on the pose of virtual objects. These changes can easily be observed on the 3D model of an immobilized controller or tracker in the VE (Figure 1).

Previous research on spatial jitter in pointing task showed that 0.3 mm average positional jitter does not affect user performance compared to a condition without jitter [8]. On the other hand, larger jitter significantly reduces the user performance, especially for pointing at smaller targets [6].

Fitts' Law

Fitts' law [4] models the human movement time between two targets. The Shanon formulation of Fitts' law [5] is defined as follows:

$$MT = a + b * log_2(A/W + 1) = a + b * ID \quad (1)$$

In equation 1, A and W are the distance to the target and its width, respectively. Both a and b terms are empirically derived constants, through linear regression. The logarithmic term in Equation 1 represents the task difficulty and is called the index of difficulty (ID).

MOTIVATION

Previous work on 2D input devices in 3D environments showed that spatial, i.e., positional jitter can significantly affect user performance [6, 7]. Extending these findings, we aim to explore the effect of 3D rotational jitter on a 6DOF controller. We hypothesize that rotational jitter has a negative effect on user performance during a 3D pointing task, especially for smaller targets with a larger index of difficulty. Based on this hypothesis, we expect that participants will exhibit increased error rates and lower throughput with increased rotational jitter.

USER STUDY

Participants. 8 right-handed subjects (4 female), on average 24.12 ± 3.13 years old, participated in the experiment. All participants were playing 3D games for 0-5 hours weekly. The interpupilary distance of the headset was adjusted individually for each participant.

Apparatus. We used a PC with an Intel (R) Core (TM) i7-5890 CPU with 16 GB RAM and a NVIDIA GeForce RTX2080 graphics card. For the VR HMD, we chose a HTC Vive Pro headset and used its controller as input devices.

Procedure. After a demographic questionnaire, participants were comfortably seated in a chair that does not allow for rotation. We used a variation of the ISO 9241-411 task, where two targets are positioned along a single lateral axis. Participants were asked to select 3D targets reciprocally as fast and as accurately as possible with their dominant hand.

In the VE, subjects were placed in a empty room (Figure 3), where gray virtual targets appeared 50 cm away from the participants at their eye level. We placed a yellow sphere at the end of a 30 cm

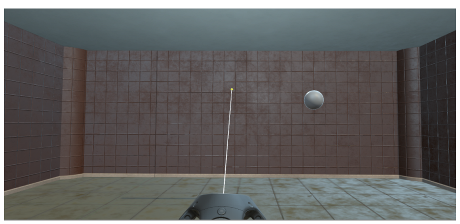

Figure 3: A screenshot taken during the experiment. Subjects were placed in an empty room which also provides visual depth cues.

ray originating at the center of the controller. We asked subjects to use this sphere as the cursor to select the targets. During the experiment, we applied uniformly distributed rotational noise as jitter at the ray's starting point as rotations around all three axes in the experimental conditions. Thus, the ray and the yellow cursor at the end of the ray were jittering together relative to the center of the controller. Also, we deliberately chose a constant ray length to avoid any potential issues with control-display gains, depth perception and contact point visibility. Further, we chose not to use "standard" raycasting, as it intersects with the surfaces of targets and thus turns the 3D pointing task into a 2D one.

Subjects pressed the trigger button of the controller to select targets. When a participant missed the target, an error sound was played in the HMD speakers and the color of the target changed to red for visual feedback. Afterwards, the next target appeared and subjects continued their task.

Subjects selected a sequence of 11 targets for each of three target sizes (target sphere diameter) and three target distances (distance between two targets). Four different jitter range conditions were counterbalanced between subjects.

Table 1: One-way RM ANOVA results

	Jitter Range	ID
Movement time	F(1.14, 7.97)= 4.78 NS	F(1.2,8.4)=25.4 ***
Error rate	F(1.35,9.4)= 188.37 ****	F(2.82,19.75)=134 ****
Effective throughput	F(3,21)=35.75 ****	F(8,56)=32.84 ****

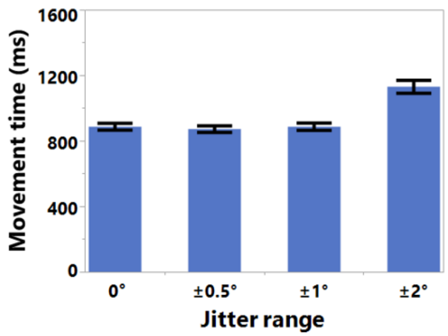

Figure 4: Movement time results for different amounts of rotational jitter.

Experimental Design. The 8 participants performed 11 trials in 36 experimental conditions: four different jitter range conditions (JR_4: 0°, ±0.5°, ±1°, and ±2°), three Target Distances (TD_3: 10, 20, and 30 cm) and three Target Sizes (TS_3: 1.5, 2.5, and 3.5 cm), which results in a JR_4 x TD_3 x TS_3 within-subject design. Subject's movement time (ms), error rate (%) and effective throughput (bit/s) were measured as dependent variables. Based on the different values for TD_3 and TS_3 in equation 1, we evaluated 9 unique ID_9s between 1.94 and 4.39. Participants repeated the experiment 3 times. Thus, each subject performed 1188 trials (JR_4 x ID_9 x 11 trials x 3 repetitions). Overall, we collected 9504 data points for each dependent variable.

RESULTS

We analyzed the results with RM ANOVA using SPSS 24. Before the ANOVA, we removed the data for double clicks (%0.7 of the data). Mauchly's sphericity test was not violated for throughput ($\chi^2(5)$ = 10.5, NS), but for movement time ($\chi^2(5)$ = 22.17, p<0.001) and error rate ($\chi^2(5)$ = 15.26, p<0.01). We used Greenhouse-Geisser correction (ϵ < 0.75) to address the sphericity violations. The one-way RM-ANOVA results for movement time, error rate and effective throughput are shown in Table 1, with **** for p < 0.0001, *** for p < 0.001, ** p < 0.01, * p < 0.05, and n.s. for not significant results.

One-way ANOVA results

Movement time. According to results of Table 1, rotational jitter did not significantly slow down the participants, as also shown in Figure 4. Even though subjects were somewhat slower with the ±2° jitter condition, this did not significantly affect their task time.

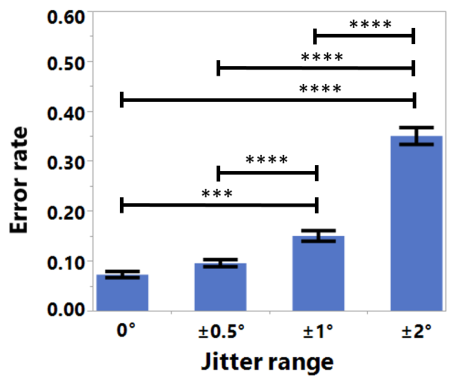

Figure 5: Error rate results for different amounts of rotational jitter.

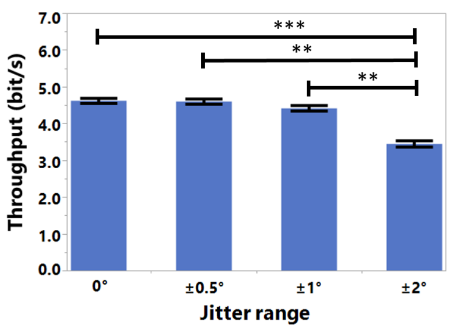

Figure 6: Effective throughput results for different amounts of rotational jitter.

Error rate. The results in Table 1 show that rotational jitter has a negative effect on error rate. Above ±0.5° jitter, subjects made significantly more errors.

Effective throughput. Effective throughput results, shown in Table 1 and Figure 6, show that rotational jitter negatively affects user performance and subjects' throughput significantly drops for ±2° jitter.

Two-way ANOVA results

There was no significant interaction between ID and jitter for movement time (F(1.93, 13.5)=2.64, n.s.) nor effective throughput (F(24,168)=1.6, n.s.), but we observed a significant interaction for error rate F(5.4, 37.6)= 18.16, p<0.0001. In more detailed analysis, we identified that target distance did not have a significant interaction with jitter range, F(6,42)= 0.72, n.s. (for the three Target Distances TD_3 and four Jitter Ranges JR_4, the sphericity assumption was not violated with $\chi^2(20)$ = 17.66, n.s.). On the other hand, target size had a significant interaction with jitter amount, F(2.07,14.5)= 93.04, p<0.0001 (for the three Target Sizes TS_3 and four Jitter Ranges JR_4, the sphericity assumption was violated with $\chi^2(20)$ = 52.6, p<0.0001 and we used Greenhouse-Geisser correction.). The interaction results are shown in Figure 7, where subject made more errors for ±2° for all target sizes. On the other hand, ±0.5° jitter did not significantly affect the error rate for all target sizes.

DISCUSSION AND LIMITATIONS

In this experiment, we analyzed how 3D rotational jitter affects user performance in a 3D pointing task. For this, we used a HTC Vive Pro HMD and it's controller in a Fitts' law experiment.

According to the results, movement time was not affected by rotational jitter. On the other hand, when we plot ID vs. movement time according to equation (1) for different amounts of jitter, the a and b values are notably different for ±2° (R^2 = 0.195 with a=-30 and b=369). These Fitts' law models for different IDs are shown in Figure 8. Based on this outcome, we speculate that with a larger experiment, we might observe significantly slower movement times for ±2° jitter.

Further, we did not observe any significant difference between ±0.5° and no jitter. This also means that small amount of rotational jitters might not (noticably) affect user performance. This result is similar to the outcome of a previous study on positional jitter [8].

Because we start to observe a decrease in human performance in the results for error rate, we can say that designers and engineers need to pay special attention to systems with more than ±0.5° rotational jitter. For ±1° rotational jitter, subjects made more errors compared to the no jitter condition.

We selected our object widths to be similar to previous 3D pointing studies [1, 2]. We also chose the jitter levels relative to static controller jitters, shown as Figure 1 and Figure 2. With such a stable controller, the worst jitter value (±2° or $\pm\pi/90$) could place the cursor up to $\pm sin(\pi/90) * 30 = \pm 1.05$ cm away from the center position, which was larger than our smallest object width (1.5 cm). This

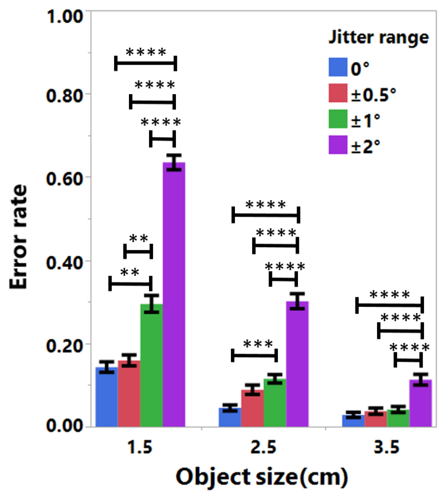

Figure 7: Error rate results for three different jitter ranges. We used the Sidak method for post-hoc analysis.

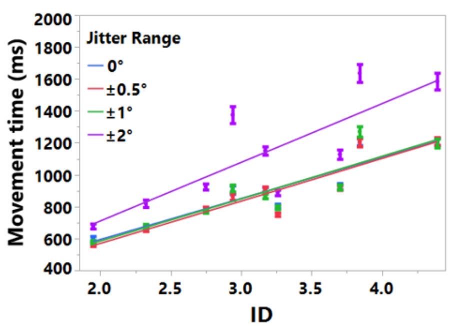

Figure 8: Fitts' law model for movement time.

illustrates that practitioners and researchers who use such 6DoF controllers for 3D pointing tasks must consider the potential effect of such jitter on the selection error rate for objects of such size. We used a ray-cast technique that shows participants the cursor position through a yellow sphere in 3D environment with visual and depth cues provided by the ray. While the constant ray length reduces the complexity of the experimental design, it does not allow us to generalize our results to other target widths and distances, e.g., for further away targets.

Moreover, we also observed a significant interaction between target size and jitter on error rate. As we hypothesized in the motivation section, performance of the participants decreased in smaller targets for larger amounts of jitter.

CONCLUSIONS AND FUTURE WORK

We performed a 3D pointing experiment to understand how 3D rotational jitter affects user performance. While we observed no significant effects for ±0.5° jitter, ±1° jitter already significantly reduced user performance in at least one performance measure, i.e., error rate. We also observed that dependent variables for measuring pointing task performance can be affected by different amounts of jitter. In our experiment, we used a 30 cm ray and added rotational jitter from the center of the controller. Different ray lengths or additional positional jitter might also alter the user performance. Furthermore, mis-calibration, hardware problems, software errors, poorly designed interaction methods, and other potential sources of noise should also be considered during the experimental design. In our future work, we will continue to explore how some of these factors affect user performance.

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