A Comparative Study of Planar Surface and Spherical Surface for 3D Pointing Using Direct Touch

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ABSTRACT

We investigated the performance of 3D pointing using direct touch in a planar surface condition (PC) and a spherical surface condition (SC). In addition, we examined the performance in terms of Fitts' law. Although the results showed that the performance in SC was slightly worse than PC, SC was higher conformed to Fitts' law than PC without the conditions involving head rotation (PC's and SC's R^2 is 0.945 and 0.971, respectively).

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; *Interaction techniques*; Pointing.

KEYWORDS

Curved surface, virtual reality, selection performance, Fitts' law

ACM Reference Format:
Naoki Yanagihara, Buntarou Shizuki, and Shin Takahashi. 2019. A Comparative Study of Planar Surface and Spherical Surface for 3D Pointing Using Direct Touch. In *25th ACM Symposium on Virtual Reality Software and Technology (VRST '19), November 12–15, 2019, Parramatta, NSW, Australia.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3359996.3364814

1 INTRODUCTION

In a VR system, virtual objects composing a user interface tend to be arranged on a plane (e.g., floating menu and virtual keyboard). However, the user's arms move curvilinearly, suggesting that the target selection performance could be improved by arranging virtual objects spherically. Various studies have investigated pointing performance on non-planar surfaces [Benko et al. 2008; Ens et al. 2014; Roudaut et al. 2011; Voelker et al. 2012].

However, to the best of our knowledge, none have investigated whether a spherical arrangement condition (SC) conforms to Fitts' law [Fitts 1954]. Furthermore, the pointing performance on SC relative to the planar arrangement condition (PC) remains poorly understood. Thus, in this study, we investigated 3D pointing performance using direct touch under PC and SC with respect to movement time, error rate, and movement distance and whether they conformed to Fitts' law.

VRST '19, November 12–15, 2019, Parramatta, NSW, Australia

ACM ISBN 978-1-4503-7001-1/19/11…$15.00
https://doi.org/10.1145/3359996.3364814

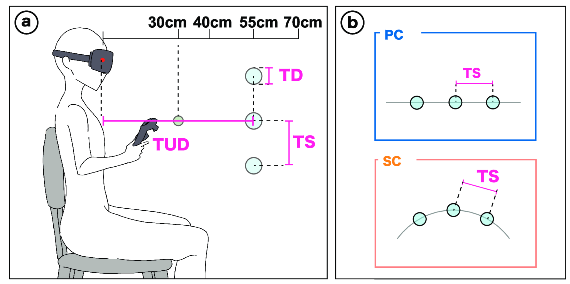

Figure 1: Setup of the user study: Overview of the user study (a) and arrangement of targets in PC and SC (b).

2 USER STUDY

We measured 3D pointing performance using direct touch under PC and SC with 12 participants.

2.1 Design

The study used a $3 \times 3 \times 3 \times 2$ within-subjects design. The independent variables were target diameter (TD = 1.5, 2.5, or 3.5 cm), target separation (TS = 10, 20, or 30 cm), target–user distance (TUD = 40, 55, or 70 cm), and surface shape (PC or SC), as shown in Figure1; these TDs, TSs, and TUDs were determined according to [Barrera Machuca and Stuerzlinger 2019]. The dependent variables were movement time, error rate (percentage of missed targets), and movement distance (the path length of the pointer from the initial target to the last target).

Participants. In total, 12 participants (10 males) were recruited to our study, age from 21 to 25 years (M = 23, SD = 1.08). Each participant was paid approximately 8 USD for their time.

Apparatus. To build the VR environment, we used an HTC VIVE (an HMD and one VR controller) and a 2.80 GHz Windows PC with an NVIDIA GeForce GTX 1060. We used Unity 2018.3.11f1 and SteamVR 1.5.16 to implement the application for the user study.

Task. Nine spheres (targets) were arranged around each participant on a planar surface under PC, and on a spherical surface under SC. Participants were asked to select a highlighted target as quickly and accurately as possible; they selected the target by moving the pointer inside it and then pressing the button (i.e., the trigger on the controller) using the index finger. The target to be selected was highlighted in yellow; the other targets were blue. When the pointer entered a correct or incorrect target, it turned red and the controller vibrated for 5 msec as a means of visual and haptic feedback. If a participant pressed the button with the pointer outside the target

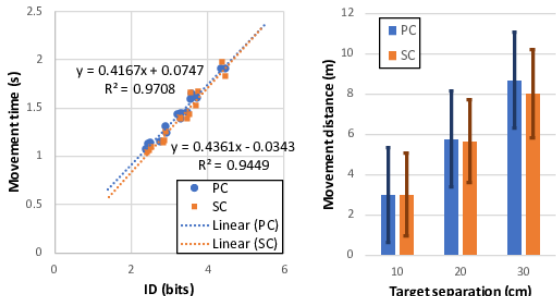

Figure 2: Movement time (left) and movement distance as a function of target separation (right).

or selected the wrong target, the trial was marked as an error and a new target appeared.

Procedure. Each participant sat in a chair and put on the HMD. They used only their dominant hand to perform the task. Six participants first performed the task in PC; the other six participants first performed it in SC. The task and procedure were first explained to participants and they then practiced 3D pointing for 5 minutes in PC. During this practice session, different values of TD, TS, and TUD were used than those in the actual experiment (TD = 2.0, TS = 10, TUD = 50). Subsequently, participants calibrated the center of a spherical surface so that it corresponded to the position of their shoulder. This calibration was performed as follows. 1) Participants extended their dominant arm out to the left side (regardless of whether they were right- or left-handed) at shoulder height while holding the controller with the dominant hand. 2) They pressed the button and then rotated the arm as if to draw a horizontal half-circle (i.e., left → front → right). 3) On completing this movement (i.e., the arm was extended out to the right side), participants released the button. The center of the half-circle, which we used as the center of the spherical surface, was estimated with a circle estimation algorithm using the controller positions captured during the calibration. The estimated shoulder position was also used to determine the position of the *initial target*, i.e., the target with which participants began the task. This target was positioned 30 cm in front of the estimated shoulder position and indicated by a green sphere.

On selecting the initial target, a timer was started and the next target appeared randomly. Participants selected a total of 18 (nine targets × two repetitions) targets during one session. Once the session had finished, the values of TD, TS, and TUD were changed for the next session; to avoid any order effect of session sequence, the values of TD and TS were changed randomly, and TUD was counterbalanced across participants. Participants were allowed a one-minute break every time they completed nine sessions. After finishing 27 sessions, participants were given another break and they then performed the task in another surface shape condition. After finishing all sessions, participants filled out a short questionnaire concerned with their impressions of each condition. Participants completed the user study in approximately one hour.

Each participant completed a total of 972 trials (18 trials × 3 × 3 × 3 × 2 conditions). Thus, we obtained data for a total of 11664 trials (972 trials × 12 participants).

2.2 Results

Under some conditions (i.e., when TS = 30, and when TUD = 40 and TS = 20), participants needed to rotate their head to look at the targets in the extravisual zone. Hence, we removed all data collected in such conditions before analyzing the results to assess how the performance of 3D pointing without head rotation.

The average movement time was 1.40 s (SD = 0.28) in PC, and 1.44 s (SD = 0.26) in SC. A Wilcoxon signed-rank performed on the movement time yielded a significant difference between PC and SC ($p = 0.692$). Figure 2 left shows the regression of movement time. We derived an R^2 of 0.945 in PC and an R^2 of 0.971 in SC. The average error rate was 15.3% (SD = 0.05) in PC and 14.5% (SD = 0.04) in SC. A t-test performed on the error rate showed no significant difference between PC and SC ($p = 0.286$). We also analyzed movement distance based on the pointer's trajectory in each condition (Figure 2 right). The average movement distances in PC were 2.98 m (SD = 0.12), 5.77 m (SD = 0.13), and 8.68 m (SD = 0.26) in TS = 0.1, 0.2, and 0.3, respectively, while the average movement distances in SC were 2.99 m (SD = 0.05), 5.65 m (SD = 0.05), and 8.04 m (SD = 0.15) in TS = 0.1, 0.2, and 0.3, respectively. A Wilcoxon signed-rank performed on the movement distance showed no significant difference between PC and SC ($p = 0.361$).

3 CONCLUSION AND FUTURE WORK

Our results showed that SC was more conformant with Fitts' law than was PC. However, the results also showed that the performance of SC was slightly worse than PC. Note the parameters of the sphere (i.e., the center position and radius) used in our user study were predefined. Therefore, adjusting the sphere radius to the user's arm length might improve 3D pointing performance in SC. Furthermore, other pairs of parameters might also contribute to 3D pointing performance in SC. Thus, in future research, we plan to investigate the effect of the center position (the participant's shoulder, elbow, and wrist position) and the radius (arm, forearm, and hand lengths) of the spherical surface on the 3D pointing performance in detail.

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