Exploring Relative Mapping for Parabolic Ground Pointing in VR: Lessons Learned and Future Directions

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Abstract

Ground pointing in VR typically relies on raycasting or parabolic pointing with absolute mappings. While relative mappings have been effective in other pointing and depth-control tasks, their role in ground pointing remains underexplored. We investigate speed-sensitive relative mappings for parabolic ground pointing and implement three variants: PITCH (controller pitch angle), PAD (trackpad-based depth control), and PAD&PITCH (combining both). In a study with target distances of up to 9 m, relative mappings reduced hand effort but compromised speed and accuracy. We suggest that perceived sensitivity scaling, offset accumulation, and controller height should be integrated into future designs.

Index Terms: Virtual Reality, Ground Pointing, Relative Mapping, Depth Control, User Study, Human-Computer Interaction.

1 Introduction

Pointing at the ground is common in VR for tasks such as teleportation and object manipulation. The current primary techniques are raycasting, which involves a straight line in the direction of the controller, and parabolic pointing, which simulates a parabolic trajectory. Both techniques are implemented based on absolute mapping, where the same parabolic curve or a straight line remains unchanged during interaction, and are commonly implemented in commercial applications such as SteamVR.

While absolute mapping maintains a rigid coupling between input and output, relative mapping adjusts pointer speed based on hand movement: slower movements offer precision, while faster movements enable rapid traversal over distance. Relative mapping techniques have been applied across a wide range of contexts to improve pointing performance, including mouse control [3], spatial hand manipulation [4], and depth control using a controller trackpad [1]. Inspired by these prior works, we aim to investigate whether relative mappings can similarly benefit ground-pointing tasks. To this end, we conducted an empirical study examining relative mapping applied to parabolic ground pointing in VR.

We explore three relative mapping designs by applying the relative mapping to pointer depth control via controller pitch (up/down tilt rotation) and trackpad back-and-forth sliding input, and implement three exploratory methods: PITCH, PAD, and PAD&PITCH. PITCH adjusts pointer distance based on controller pitch angle, with depth travel speed reacting to the pitch angular velocity. PAD does so through trackpad sliding, with depth travel speed reacting to the finger sliding speed on the trackpad. PAD&PITCH combines both methods as modular components. In a controlled study with 20 participants, we compared these techniques against conventional absolute approaches (raycasting and SteamVR parabolic pointing) across multiple distances and postures.

2 Implementation Details

We adopt the implementation of existing depth control functions from the state-of-the-art technique with linear interpolation [1]. Gain values and thresholds were optimised via pilot tests. The techniques were kept minimally complex to isolate the effects of relative depth control without confounding factors. Detailed implementation is available in the digital appendix.

PITCH controls the depth with the pitch angle of the controller. Pitching the controller upward moves the pointer farther along the controller's projected forward direction on the ground (and vice versa). Depth is calculated each frame by multiplying the change in pitch by a base gain of 0.1. This gain is doubled when the pitch speed exceeds 15°/s, and further multiplied by 1.2 when the pitch angle exceeds 15° (compensating for uncomfortable hand postures). PAD controls depth through the trackpad. Sliding the finger forward or backwards on the trackpad adjusts depth. The depth offset is computed by multiplying the trackpad's Y-axis displacement (per frame) by a base gain of 2.5, doubled when the sliding speed exceeds 1 m/s. PAD&PITCH is a combination of PITCH and PAD. RAYCAST, the standard implementation of the straight raycast along the controller's forward direction. STEAMVR, the absolute mapping of parabolic pointing adopted from SteamVR. For all techniques, controller location and rotation were 1€-filtered [2].

3 User Study

We designed a ground-pointing selection task to compare the Techniques (RAYCAST, STEAMVR, PITCH, PAD, and PAD&PITCH) in terms of selection speed, accuracy, and effort. Participants performed the task in both standing and sitting postures (the order of technique x posture was Latin Square counterbalanced).

Target configurations spanning multiple distances and directions (cf. Figure 1b). Participants were presented with three sphere clusters placed on the ground (Figure 1; 1m radius, centred at 2, 5, and 8m distance; 30 spheres pseudo-randomly distributed in each cluster, each sphere with 8 cm radius). For each of the 600 trials (10 per combination of 2 postures $\times$ 6 distance&directions for each of the 5 Techniques), a sphere was highlighted as the target (randomly selected within the cluster), and the participant pointed at it using the technique. The study was a within-subject design.

Participants rated the best and worst techniques at the end of the study. Data was collected from 20 participants (11 female; aged 20–43, $M = 26.35$, $SD = 5.87$) from local university. Outlier trials in time and endpoint distance (± 3 SD; 2.08%) were removed.

We conducted one-way repeated measures ANOVAs ($\alpha = .05$) with *Technique* as independent variable. Normality was assessed via Shapiro–Wilk and Q–Q plots with violations addressed via

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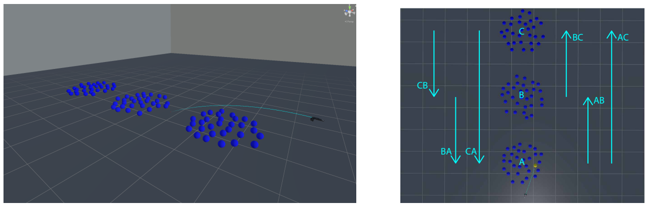

(a) Side View. (b) Top View.

Figure 1: (a) Participant's position in the task scene, indicated by the black controller. (b) Participants performed selections across the three sphere clusters (A, B, C), with different combinations of two clusters and directions.

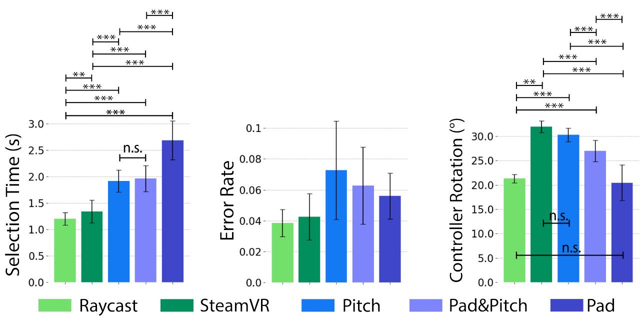

Figure 2: Selection time, error rate, and accumulated controller rotation per technique. Error bars represent 95% confidence interval.

Aligned Rank Transform. Sphericity was tested with Mauchly's test with Greenhouse-Geisser corrections. Bonferroni-corrected post-hoc tests were conducted where appropriate.

4 Results

Figure 2 outlines core results. Selection time is the time interval between the target being highlighted and the moment the trigger is pulled. We found a significant main effect on Technique ($F_{2.07,39.30} = 44.246, p < .001, \eta_g^2 = .485$)). Post-hoc tests revealed that RAYCAST was the fastest (all p $\geq$ .004), followed by STEAMVR (all p $\geq$ .004). PITCH and PAD&PITCH showed no significant difference (p = 1) and both were slower than STEAMVR (all p $<$ .001). PAD was the slowest (all p $<$ .001).

Errors were counted if the trigger was pulled while the pointer was not on the target. We found a significant main effect of Technique ($F_{4,76} = 2.892, p = .028, \eta_p^2 = .132$), post-hoc tests showed no significant difference (all p $\geq$ .120).

Accumulated controller rotation is the sum of the angle changes between controller forward directions across frames within a trial. We found a significant main effect of Technique ($F_{4,76} = 81.421, p < .001, \eta_p^2 = .811$)). Post-hoc analysis showed the highest controller rotation with STEAMVR and PITCH (all p $<$ .001), with no significant difference shown between the two (p = .368), followed by PAD&PITCH (all p $<$ .001). PAD and RAYCAST required the least (all p $<$ .001) with no significant difference shown between the two (p = 1).

STEAMVR was most preferred overall (9 best, 2 worst), followed by PAD&PITCH (7 best, 3 worst). RAYCAST received moderate support (3 best, 1 worst), while PITCH was neutral (2 best, 2 worst). PAD was least preferred (0 best, 13 worst).

5 Discussion & Conclusion

Our results indicate that compared to both absolute mapping baselines, the three relative mapping techniques did not yield significant improvements in speed or accuracy. While they required less effort than the absolute parabolic technique, the raycasting technique remained the least effortful overall. We suspect that this was caused by the naively designed speed-sensitive relative mapping did not match users' embodied strategies for ground pointing. There were several factors that we found were overlooked and under-addressed:

- **Perceived Sensitivity**: Given the same depth control sensitivity, participants found the pointer overly sensitive at close range and too slow for far targets (P2, P15, P17). This mismatch made depth control feel inconsistent and hard to manage.
- **Offset Accumulation**: We found participants suffered from offset buildup due to the lack of clutching with PITCH. As interaction progressed, some held the controller at extreme pitch angles, either too high or too low. While high angles made the control sensitive, lower angles led to better speed and satisfaction.
- **Controller Height and Depth Control**: With the absolute parabola, we found that participants primarily refined the pointer by lifting the controller up and down instead of the pitch rotation. Our design of relative mapping overlooked this height dimension and prevented participants from leveraging their natural physics intuition, which may explain its limited impact on accuracy.

These findings suggest that future implementation could be designed as depth-dependent, which integrates a scaling factor that reacts to the current depth or visual size of the cursor, thereby balancing this effect. In addition, adopting offset management could help mitigate offset accumulation and maintain the controller at a lower pointing angle to optimise PITCH's performance. Furthermore, incorporating controller height input may enable finer and more natural depth refinement by better aligning with users' embodied interaction strategies. Finally, given the strong performance and intuitive nature of absolute mappings, future work could explore hybrid designs that combine absolute parabolic pointing with relative refinements, rather than relying solely on relative control.

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Digital Appendix

We provide open-source code, a demo Unity project, a video figure, and the raw data for further experimentation: `https://doi.org/10.5281/zenodo.18375690`.

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