Force Feedback and Visual Constraint for Drawing on a Terrain: Path Type, View Complexity, and Pseudohaptic Effect

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ABSTRACT

We evaluated stylus-based force feedback and a visual constraint alternative for marking paths on a terrain dataset. We further considered effect interactions with factors affecting task difficulty, including path difficulty related to contact geometry and indirect viewing. For example, the performance benefit of force feedback (relative to visual constraint) was minimal when the path lacked laterally-reinforcing geometry. We also show the visual constraint may generate a pseudohaptic effect: subjects report significantly more touch sense than for a no-force condition.

KEYWORDS: Force feedback, virtual reality, pseudohaptics.

INDEX TERMS: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O

1 INTRODUCTION

For terrain datasets, a basic annotation task is to draw on a mesh to mark geological features or a proposed construction path. This may benefit from force feedback to help position a tool (e.g., [1]).

We evaluated both standard force feedback and a constrained-motion marking tool alternative. Beyond a basic evaluation of feedback methods, our work considers how their effects relate to different task complexities found in our data exploration system. Additionally, we investigated the possibility of a pseudohaptic effect [2] for the constraint method. Such effects may improve subjective experience or influence motor control near surfaces.

Our annotation system, shown in Figure 1, includes visual and force feedback. Users draw by moving a stylus to a terrain, generating projected polylines. In addition to the main mesh view, datasets are viewable in auto-arranged secondary view boxes, described in [3]. For our evaluation, secondary views showed hidden mountain sides via mirrored presentations in the boxes.

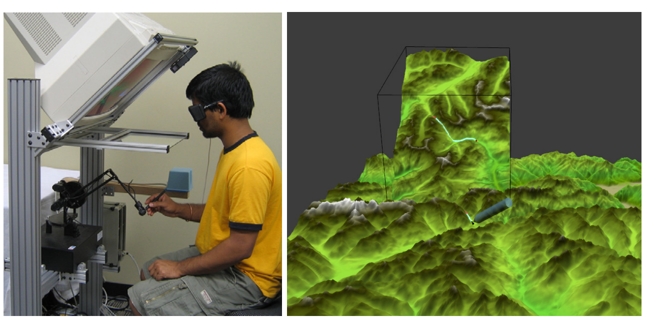

Figure 1. Left: Mirror-based 3D display and force stylus. Right: User's view of a terrain with a box providing a secondary view.

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2 EXPERIMENT

2.1 Independent Variables, Apparatus, and Subjects

We conducted a within-subjects study to evaluate the different feedback types for the path tracing task described in [3]. Part of each path was visible in the main view, but the remaining part was visible only in the secondary view box. Our study focused on performance for the path portion hidden from the main view. We used the apparatus seen in Figure 1 and detailed in [3]. Sixteen subjects participated: 12 male and 4 female. Subjects were primarily students in technical fields. Median age was 24 years.

For an objective experiment portion, the independent variables, producing 12 level combinations (conditions), were:

1. *Force feedback mode* (force, pseudo, none): In a minimal no-force approach (none), drawing occurs when stylus tip is within a threshold distance of the surface. For standard force feedback rendering (force), we use a penalty-based method with force shading: force magnitude is proportional to the stylus tip's vertical distance below the surface, and direction is an interpolated surface normal. Pseudo force mode, the visual constraint alternative to force feedback, visually prevents the stylus from moving below the surface with a temporary vertical offset to stylus position.
2. *Path* (simple, difficult): Two paths were used for tracing (Figure 2). One is along a groove-like feature (simple). The other path is moderately bumpier and lacks geometry that would help control horizontal motion with lateral force feedback (difficult).
3. *Reach mode* (reach-in, no reach-in): There were two different locations for tracing with respect to a secondary view box, with different complexities in terms of view directness. In the reach-in case, the user reaches into the secondary view box to trace. In the no-reach case, the hand remains at the main mesh while the user can view the interaction in the secondary view, requiring mapping of motions or reliance on other cues such as forces.

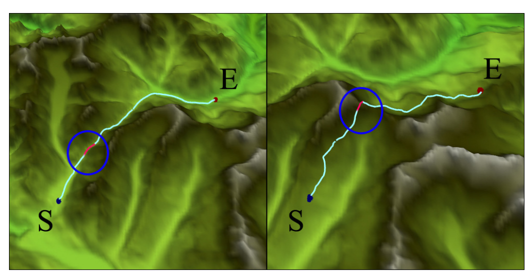

Figure 2. Simple (left) and difficult (right) paths (viewpoint differs from experiment for clarity). "S" and "E" show start and end. Circles show a transition beyond which the path is hidden from the main view. Transition-to-end length is the same for both.

2.2 Procedure

Objective Performance Experiment: Subjects first performed 8 practice trials. This was followed by two experiment sessions, each with 4 practice trials and 12 regular trials (12 condition combinations). In one session, randomly per subject, the scene (except the interaction tool handling) was mirrored left-to-right.

Per trial, subjects traced a path. Guiding arrows and colored marks denoted different task points as described in [3]. At a transition point, the subject either reached into the secondary view (reach-in) or used it only as visual reference (no reach-in).

Condition order was randomized per session, but reach mode switching was minimized by requiring the first 6 trials per session to be either all reach-in or all no-reach (random per subject). Each reach mode began with two practice trials as a reminder.

Subjective Force Rating Experiment: A 12-trial subjective session was also conducted. Trials were again randomized with minimized reach mode switching. Per trial, the subject answered the following question on a scale from 1 (no touch sense) to 5 (strong touch sense): *As you trace this path, how much sense of touch do you experience from contact with the surface?*

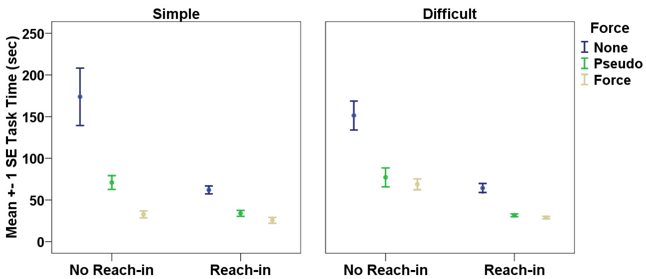

Figure 3. Task Time: time to trace hidden path portion.

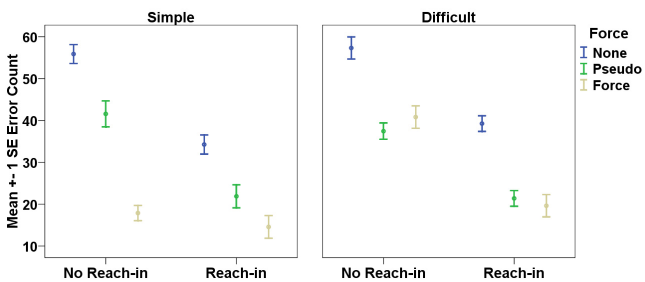

Figure 4. Error Count: number of times subject moved off path.

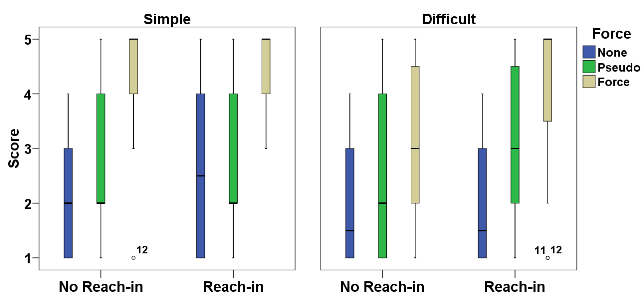

Figure 5. Touch sensation strength, box-and-whiskers plots.

3 Results

Performance, shown in Figures 3 and 4, was analyzed with 3-way repeated-measures ANOVA and Bonferroni-corrected followups.

Task time: Force mode impacted task time ($F(2,30) = 39.169$, $p < .001$). Pseudo mode reduced time compared to no force ($p < .001$), but standard force feedback had even faster time ($p = .01$).

Task time was also faster when subjects reached in to the box view, compared to no-reach ($F(1,15) = 26.462$, $p < .001$).

There was no overall detected effect for path type ($F(1,15) = .668$, $p = .427$), but there were interactions involving path type. There was path-force interaction ($F(2,30) = 3.705$, $p = .036$), with path having a detected effect in only standard force mode ($F(1,15) = 34.894$, $p < .001$), where the simple path had 40% lower time.

There was reach-force interaction ($F(2,30) = 8.832$, $p < .001$) with larger force mode differences in no-reach cases, but with a reach-force-path interaction trend (near-significant: $F(2,30) = 3.152$, $p = .057$). The no-reach standard-force difficult-path result shows notably slow time compared to other standard force cases.

Error count: Every independent variable affected error overall (Force: $F(2,30) = 214.170$, $p < .001$; Path: $F(1,15) = 23.311$, $p < .001$; Reach: $F(1,15) = 79.743$, $p < .001$). Pseudo force mode reduced errors over no force ($p < 0.001$) by 35%, and standard force feedback reduced errors further ($p < 0.001$) by 24%.

There was path-force interaction ($F(2,30) = 15.810$, $p < .001$). Again, path had a detected effect particularly in the standard force mode ($F(1,15) = 52.354$, $p < .001$).

There was reach-force interaction ($F(2,30) = 7.487$, $p = .002$) and reach-force-path interaction ($F(2,30) = 10.807$, $p < .001$) that is most visible in the no-reach difficult-path standard-force result.

Subjective rating results: Touch sensation strength ratings are shown in Figure 5. We computed scores per force mode per subject as the average of that subject's ratings for the force mode. Pairwise Wilcoxon Signed Ranks tests compared scores.

Subjects reported more sense of touch for the pseudo force mode than for the no-force mode ($Z(16) = -2.791$, $p = .005$). However, touch with pseudo mode was not reported to be as strong as with force feedback ($Z(16) = -3.252$, $p = .001$).

4 Discussion and Conclusion

Based on plots, pseudo force (visual constraint) performs more closely to standard force feedback than to no force, with only small difference for the more difficult path. In the most difficult condition (no reach, difficult path), there was no notable performance benefit of standard force feedback over visual constraint. In the no-reach cases, subjects rely on lateral force guidance when present but perform relatively poorly otherwise.

Visual constraint appears to be a reasonable alternative when force feedback is not available, and especially when geometry does not generate lateral force cues. A possible disadvantage of the visual constraint is that it can require more vertical motion to lift a tool after marking. We expect this is minor compared to the difficulty of the no-force mode, and visual feedback can include an indicator of penetration distance or "force".

Subjective ratings provide evidence of a pseudohaptic effect of the visual constraint: users report increased touch sense compared to the no-force case. Anecdotally, the authors have experienced pseudohaptic effects at initial contact and during elevation changes (e.g., bumps). Further study could evaluate this more objectively and determine impacts on users during dataset annotation, e.g., by comparison to a method that visually displays real tool pose but marks as though the constraint is present.

Regardless of performance differences or lack thereof, we would expect users to usually prefer standard force feedback because it provides the strongest sense of touch. As an exception, more extreme paths with frequent dramatic bumps could negatively impact both performance and subjective experience sufficiently that the visual constraint would be preferred.

References

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