Augmented Reality Fitts' Law Input Comparison Between Touchpad, Pointing Gesture, and Raycast

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2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) | 978-1-6654-8402-2/22/$31.00 ©2022 IEEE | DOI: 10.1109/VRW55335.2022.00146

Abstract

With the goal of exploring the impact of transparency on selection in augmented reality (AR), we present a Fitts' law experiment with 18 participants, comparing three different input methods (finger based Pointing Gesture, controller using the Touchpad, and controller using Raycast), across 4 different target transparency levels (0%, 30%, 60%, and 90%) in an optical see-through AR head-mounted display. The results indicate that transparency has little effect on selection throughput and error rates. Overall, the Raycast input method performed significantly better than the pointing gesture and Touchpad inputs in terms of error rate and throughput in all opacity conditions.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction techniques—Pointing; Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality

1 Introduction

As the use of augmented reality (AR) continues to increase, the need for accurate interaction methods becomes more and more salient. Optical see-through (OST) AR head mounted displays (HMDs) use computer generated graphics superimposed over a set of see through lenses to display virtual elements overlaid on reality. Two popular consumer grade HMDs are the Magic Leap One and the Microsoft Hololens 2, both of which are self contained units that require no external computer to operate.

The benefit that AR-HMDs provide over traditional displays is that visualizations are presented on top of the user's normal vision, allowing almost instant access to information. Adjusting transparency of these visualizations can also offset ambient brightness, which can either reduce (e.g., when used outside) or increase (e.g., when used inside) virtual content visibility. While this trade off between virtual transparency and real-world occlusion can be beneficial, the impacts of transparency on target selection are as of yet unknown. Some studies have looked at the impact of transparency in selection [1, 2, 4] and found that it had little impact on selection performance; However these studies did not employ the use of Fitts' Law to study performance in AR.

We present a study examining the degree to which target selection performance - as predicted by Fitts' law - is affected by varying transparency levels across different input methods to control the selection cursor. Fitts' law is a model of psychomotor behavior that classifies rapid aimed movements based on their rates of information processing in humans. It has been used to study differences between novel input devices and interaction techniques. Our experiment used the Magic Leap One running custom software. This application presents an 11 target Fitts' law 2-dimensional (2D) reciprocal selection task for each transparency level (0%, 30%, 60%, 90%) for all three of the input modalities tested. These input modalities are representative of the most common selection methods currently used with the Magic Leap One. The input modalities included – `Touchpad`: uses the touchpad on the Magic Leap controller with a position-control mapping to control a 2D planar cursor. `Raycast`: casts a ray from the Magic Leap controller in the direction it is facing. And, `Pointing Gesture`: uses a pointing gesture, places the cursor at the end of the user's dominant pointer finger, relative to the middle of the head [3].

The key contributions of this work are: (1) the first study to systematically explore the effects of target transparency in AR-based target selection. And (2) The first systematic Fitts' law based study of common AR selection techniques.

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2 Methodology

We examined how user performance in a Fitts' law 2D pointing task in AR is affected by input modality (Touchpad, Pointing Gesture, and Raycast) across four target transparency levels (0%, 30%, 60%, and 90%). Due to the limited FoV of the Magic Leap One (40x30 degrees), both the target distance (A) and width (W) were held constant (237.55cm and 46cm respectively) in all trials. The spheres and cursor reside on a 2D plane that always remains in front of the participant to keep them from having to search for a target sphere outside their initial field of view; as doing so would introduced a secondary search task.

Participants – This study consisted of 18 volunteers (6 female, 12 male). Ages ranged from 18 to 47 (Mean = 24.88, SD = 6.71). The two remote participants were emailed the application to run on their own devices [5]. One participant was left handed. No participants had any previous experience with the system. All reported having either normal or corrected to normal vision.

Materials – Our experiment was conducted using a Magic Leap One OST AR-HMD along with the default controller. We developed custom software to run on the Magic Leap One using the Unreal Engine v4.24.3. The Touchpad input modality used the controller's touch-based joypad in a position-control mapping (isotonic) to the 2D plane the cursor and target spheres reside in. A gain of 40x was applied to the Touchpad coordinates so that the edges of the Touchpad mapped to the edges of the ring of target spheres. All input methods used the same buttons (shoulder button or trigger) to select/ click the targets and only differed in how the cursor is manipulated. In the case of the Pointing Gesture input, target selections were made using the controller in the non dominant hand.

Procedure – Participants first completed an informed consent form and receive a participant-ID before completing a demographics questionnaire. The experimenter then described how the experiment worked along with how to use each input modality. In the case of the remote participants, this was done via a recorded video. After this, the participant put on the HMD while standing 1 meter away from the white wall. Before starting the experiment, participants first completed a practice step for each input modality.

Design – This experiment employed a within-subjects design with two independent variables: ***Input Modality:*** Touchpad, Pointing Gesture, Raycast and ***Transparency Level:*** 0%, 30%, 60%, 90%.

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DOI 10.1109/VRW55335.2022.00146

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Input modality ordering was counterbalanced via Latin square. Transparency Level ordering was randomized at the start of each new input modality by shuffling an array that contained each level. Each participant completed a total of 10 selections per trial x 4 transparency levels x 3 inputs = 120 selections, or 2160 selections over all 18 participants. The dependant variables were as follows – **Throughput:** bits per second, calculated based on the ISO 9241-9 standard. **Movement Time:** average time it took to select each target, in milliseconds. **Error rate:** average number of selections that missed. **Target Re-entry Count:** average re-entries made on target by cursor. And, **Incorrect Click Count:** average number of clicks made before selection.

3 Results

We analyzed the data using repeated-measure ANOVAs along with Tukey HSD post hoc tests at the 5% significance level when normality was met. Normality was accessed with the Shapiro-Wilk normality test at the 5% significance level as well as visually with QQ plots. When the assumption of normality could not be met, we used the the Kruskal-Wallis rank sum test with a Dunn post hoc comparison instead. This led to a square root transform of throughput data and a inverse transformation of the movement time data. Any trial that had an outlier in the movement time, re-entry count, or incorrect click count category that was beyond three standard deviations from the mean was removed.

Throughput – The ANOVA revealed that the main effects of input type on throughput was statistically significant ($F_{2,30} = 39.97$, $p < .001$). Neither the effect of transparency ($F_{3,47} = 0.33$, ns) nor the input type × transparency interaction effect ($F_{6,95} = 1.22$, p ¿ .05) were found to be significant on throughput. We conducted Tukey HSD post hoc tests which indicated that the Raycast input modality ($M = 2.63$, $SD = 0.71$) offered significantly higher throughout than both the Pointing Gesture ($M = 1.51$, $SD = 0.44$) and Touchpad ($M = 1.78$, $SD = 0.70$) inputs. We found no significant differences between the Pointing Gesture and Touchpad input modalities.

Movement Time – The ANOVA revealed that the main effect of input modality on movement time was statistically significant ($F_{2,30} = 46.61$, $p < .001$). Neither transparency ($F_{3,47} = 0.35$, ns) nor the input modality × transparency interaction ($F_{6,95} = 1.33$, p ¿ .05) had a significant effect on movement time. Post hoc analyses again revealed that the Raycast input modality ($M = 1068.77$, $SD = 418.19$) took significantly less time than both the Pointing Gesture ($M = 1813.77$, $SD = 506.37$) and Touchpad ($M = 1563.06$, $SD = 675.03$) input modalities. No significant differences were found between the Pointing Gesture and Touchpad input modalities.

Error Rate – A Kruskal-Wallis rank sum test with a Dunn post hoc comparison revealed that the main effect of input modality on error rate was statistically significant ($H(2) = 10.55$, $p < .006$). Neither the main effect for transparency ($H(3) = 2.92$, p ¿ .05) nor the input type × transparency interaction effect ($H(11) = 19.55$) were found to be significant. Dunn's multiple comparisons test indicated that Raycast ($M = 0.01$, $SD = 0.03$) had significantly lower error rates than Touchpad ($M = 0.05$, $SD = 0.08$). We also found a significant ($p < 0.01$) difference between Raycast and Pointing Gesture ($M = 0.04$, $SD = 0.06$). We found no significant differences between the error rates of the Pointing Gesture and Touchpad input modalities.

Target Re-Entry Count – A Kruskal-Wallis rank sum test with a Dunn post hoc comparison revealed that the main effects of both input type ($H(2) = 52.70$, $p < .001$) and the transparency x input type interaction ($H(11) = 56.87$, $p < .001$) had a statistically significant impact on average re-entry count. Transparency was not found to have a significant main effect on average re-entry count ($H(3) = 0.54$). Dunn's multiple comparisons test indicated that significantly more re-entries occurred with the Pointing Gesture input ($M = 1.06$, $SD = 1.08$) than in the Touchpad ($M = 0.23$, $SD = 0.30$) or Raycast ($M = 0.28$, $SD = 0.30$) inputs. No significant differences were found between the Raycast and Touchpad inputs.

Incorrect Click Count – The Kruskal-Wallis rank sum test to analyze incorrect click count. No significant differences were found between groups. There were only 22 total incorrect clicks (Pointing Gesture: 12, Raycast: 4, Touchpad: 6) out of all trials, as most clicks were captured as a miss if they were within a reasonable area around the target (2x the radius).

Post-Questionnaire – We administered a post-questionnaire to the participants which asked six ranked choice questions about preference in input modality. The results show that Raycast was voted the preferred overall method (N= 17) as well as the preferred for extended use (N = 14). Touchpad was voted the preferred input method in a crowded environment however (N = 10). Raycast was also voted to feel the most natural (N = 14), accurate (N = 16), and the fastest (N = 16). At the end of the questionnaire we had space for any other comments participants had. Three participants indicated that the Pointing Gesture condition yielded a high level of fatigue. Three participants also indicated tracking issues in the pointing gesture condition.

4 Conclusion and Future of Work

We conducted a Fitts' law study comparing three different input modalities, across 4 different levels of target transparency in AR using the Magic Leap One OST AR-HMD. The four transparency levels were 0%, 30%, 60%, and 90% transparent. The input modalities we examined were finger based Pointing Gesture selection, controller with Touchpad, and controller with Raycast. We did not find a significant effect on throughput, movement time, incorrect click count, or error rate due to transparency. However, the Raycast input modality (2.63 bits/s, 1.25% error rate) performed significantly better than the Pointing Gesture (1.52 bits/s, 3.69% error rate) and Touchpad (1.78 bits/s, 4.79% error rate) input modalities in terms of error rate and throughput in all opacity conditions.

Future work could test the impact of lost finger tracking, due to users leaving the tracked area, on task re-acquisition time. It may be that realizing that tracking was lost caused users to create more errors or delays by attempting to re-capture that input. Also, one could examine the impact of display type and transparency on target selection to see how well these results transfer to other AR-HMDs.

Acknowledgments

The research was supported by NSF 2106590, 2016714, 2037417, and 1948254

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