Field of View Effect on Distance Perception in Virtual Reality

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Abstract

Recent state-of-the-art Virtual Reality (VR) Head-Mounted Displays (HMD) provide wide Field of Views (FoV) which were not possible in the past. Due to this development, HMD FoVs are now approaching a level that parallels natural human eyesight. Previous efforts have shown that reduced FoVs affect user perception of distance in a given environment, but none have investigated VR HMDs with wide FoVs. Therefore, in this paper we directly investigate the effect of HMD FoV on distance estimation in virtual environments. We performed a user study with 14 participants who performed a blind throwing task wearing a Pimax 5K Plus HMD, in which we virtually restricted the FoV to 200°, 110°, and 60°. We found a significant difference in perceived distance between the 200° and 60° FoVs, as well as between the 110° and 60° FoVs. However, no significant difference was observed between 200° and 110°. Our results indicate that users tend to underestimate distance with the narrower FoV.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Human-centered computing—User studies;

1 Introduction

The increasing prevalence of Virtual Reality (VR) in the recent years, as well as its practical uses in accessibility and education [5, 10], highlights the need for a precise and intuitive representation of a virtual environment. In the past decades, researchers have noted that people tend to underestimate distances when they are using VR [7]. Many factors have been identified to have a potential effect on user perception - either by themselves or combined - including head-mounted display (HMD) traits such as weight, screen resolution, and field of view (FoV) [9]. HMDs of the past such as the nVisor SX exhibited restricted FoVs and grainier screen resolution, but modern devices such as the Pimax include a crisp resolution and a FoV which nearly parallels that of natural human eyesight as well as a large resolution. In our study, the user wears an HMD that has a wide FoV, and different FoVs are emulated within the same device. The weight of the headset is constant for the different FOVs, the VE has the same resolution for all FOVs, and meets the native resolution of the headset. We captured 360° images of our test environment at three different heights to compensate for different user heights. Therefore, we were able to isolate the effect of FOV in the VE.

2 Study

We conducted a user study to measure distance estimation when viewing a VE, with various FoVs. To evaluate distance perception, we utilized a blind throwing task in which users were asked to toss a bean-bag towards a specified target. We conducted a 3x4 within-subjects user study; the independent variables were FoV and distance. The FoV levels were 200°, 110°, and 60°. We chose these FoVs to match those of HTC Vive (110°) and NVIS nVisor ST60 (60°) which have been used in previous research [2, 3, 9]. We programmatically simulated 110° and 60° FoVs in the headset using the Unity3D game engine. The distance levels were 3m, 4m, 5m, and 6m; these distances were influenced by prior work [6, 8]. This resulted in 12 different conditions in which we measured user responses. Each user performed a bean-bag toss 3 times for each condition, and the mean error (distance from the target) was recorded. This resulted in 36 trials which were randomized for each participant.

Subjects: We recruited a total of 18 participants, but 4 participants were excluded as they were unable to pass an eye exam. The final participant pool consisted of 14 users (3 female, 11 male) with ages ranging from 18 to 39 (M=22.21, SD=3.19) and heights between 154cm and 188cm (M=175.23, SD=10.91).

Apparatus: We used a Pimax 5k Plus VR headset with a field of view of 200° (diagonal). This headset has a resolution of 2560×1440 per eye with a refresh rate of 120hz, and it weighs 470g The headset was connected to a PC equipped with an Intel 10700k CPU, an Nvidia 2080Ti GPU, and 32GB of memory. The bean-bags used for the study weighed approximately 465g and had approximate dimensions of 15cm×15cm×4cm.

Since most 360° cameras have a resolution lower than that of the Pimax, and since video see-through cameras (such as ZED Mini) could not cover the FoV of the Pimax, we decided to capture multiple images using a DSLR camera and stitch them into an equirectangular 360° image with a resolution of 30000×15000. We captured the 360° images of the environment using a Canon 7D paired with a 10mm-18mm lens where 10mm was used. The images were stitched together using the Hugin photo stitcher program. We captured 3 images at 3 different heights (151cm, 163cm, and 175cm) and used the appropriate image per participant, based on the their height. The 360° image was displayed to the user using Unity3D.

The four targets were marked with letters A, B, C, and D – A being the closest. The furthest target was 6 meters away from the user and there was 1.8m distance between this target and the closest non-study object. There was at least 1.3m empty space on each side of the targets and the ceiling was approximately 3m high.

Procedure: The participants were asked to review a consent form before the study began and we verbally asked for their consent. Then, we measured and recorded users' vision acuity for each eye using a Snellen Chart to ensure they had adequate eyesight to complete the study. The user's demographics (age, gender, and VR experience) were also collected. We described the task and objective of throwing the beanbags to the user and showed them the headset's adjustments.

Before using the headset and performing the tasks, users were asked to practice by throwing 5 beanbags at 4 different targets (20 throws in total) without wearing the headset. These targets were placed at the same distance of the actual target, but were not in the same location. We also described to the participants that we only count the initial contact point of the beanbag with the ground and if it bounces or slides only the first contact point would be measured. Since the users body is not visible in the VRE, we created a cloth collar to prevent users from seeing their body, and the users were asked to wear it during the practice throws.

Then users were asked to wear the headset to perform the tasks. Before each toss, the FoV of the headset was changed by a researcher based on the pre-generated sequence of trials, and the target name was announced to the user. Then the user threw the beanbag at the

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Table 1: Descriptive statistics of average user error, by FoV and Target Distance

FoV	Target Distance	Error (centimeters)
200°	3 meters	M = 13.9, SD = 47.5
	4 meters	M = 7.70, SD = 67.0
	5 meters	M = -9.00, SD = 74.0
	6 meters	M = -14.9, SD = 61.4
110°	3 meters	M = 11.7, SD = 66.2
	4 meters	M = -3.60, SD = 65.9
	5 meters	M = -3.50, SD = 79.3
	6 meters	M = -37.9, SD = 80.2
60°	3 meters	M = -10.4, SD = 47.2
	4 meters	M = -22.1, SD = 81.4
	5 meters	M = -19.1, SD = 78.6
	6 meters	M = -40.6, SD = 89.9

target and the researcher used a tape measure to obtain the distance between the impact point and the target. Since users were unable to receive feedback (as the image they saw was static), they were not required to close their eyes during the toss. Underthrows were recorded as negative numbers and overthrows as positive numbers. If the bag was tossed to the side, the landing spot was transposed to align it with the line from the participant to the target. The beanbag was collected by a researcher after the measurement. The participants received 5USD in cash after the study.

2.1 Data Analysis Approach

Since our study design was within-subjects, we first performed a Shapiro-Wilks test and found that the data was not normally distributed ($p < .001$). Thus, we elected to use Friedman tests as our omnibus - one for FoV, and one for Distance. In presence of statistical significance, we used Wilcoxon Signed Rank tests to compare the conditions. We used Holm's Sequential Bonferroni Adjustment to control for Type I errors . We did not hypothesize an interaction effect and therefore we did not test for one.

3 Results

Table 1 shows the descriptive statistics of average user error. As the data suggests, participants made greater error and thus underestimated the distance for narrower FoVs, and the error for further targets is greater.

We performed a Friedman test for each independent variable. First, we found a significant effect of FoV on user distance perception, $\chi^2(2) = 15.57, p < .001$. We performed post-hoc Wilcoxon signed rank tests, comparing each condition pair. We found a significant difference between the 200° and 60° conditions, as well as 110° and 60° conditions. However, we did not find a significant difference between 200° and 110° (see Table 2). Our results indicate that restricted FoVs are more conducive to distance compression, whereas the larger FoVs help to reduce error.

Next, we performed a Friedman test on the data for Distance, and found a significant effect, $\chi^2(3) = 41.61, p < .001$. We therefore performed post-hoc Wilcoxon signed rank tests, comparing each condition pair; see Table 2. We found significant differences in user error between each target distance, with one exception; 4m was not found to be significantly different than 5m. As expected, greater target distance was conducive to greater user error.

4 Discussion and Conclusion

The effect of restricted FoV on distance judgement is one of the problems that has different answers among the literature. While some historical studies have suggested that FoV - when combined with other HMD traits (weight and resolution) - does have a significant effect on distance estimation [1,9], there are other studies that suggest FoV is not a significant factor that causes compression in distance estimation [4]. In our work, we simulated reduced FoVs within one headset, therefore keeping screen resolution and weight

Table 2: Post-hoc Wilcoxon Signed-Rank Tests Results

C1	Mean	SD	C2	Mean	SD	t-test Result
Effect of Field of View						
200°	-0.56	74.29	60°	-23.04	81.11	$Z = -4.071, p < .001$
200°	-0.56	74.29	110°	-8.32	84.24	$Z = -1.089, p = .276$
110°	-8.32	84.24	60°	-23.04	81.11	$Z = -2.994, p < .01$
Effect of Distance						
3m	5.08	61.63	4m	-5.97	88.80	$Z = -3.571, p < .001$
3m	5.08	61.63	5m	-10.54	85.61	$Z = -3.126, p < .01$
3m	5.08	61.63	6m	-31.13	88.80	$Z = -5.168, p < .001$
4m	-5.97	82.26	5m	-10.54	85.61	$Z = -0.681, p = .496$
4m	-5.97	88.80	6m	-31.13	88.80	$Z = -3.723, p < .001$
5m	-10.54	85.61	6m	-31.13	88.80	$Z = -3.209, p < .01$

constant, finding a significant main effect of FoV such that reduced FoVs resulted in distance compression. Although user error was greater in the 110° condition compared to the 200° condition, we note that these two conditions were not statistically different. Therefore, this implies that newer hardware which boasts a FoV similar to that of natural human eyesight may not provide a benefit in terms of distance estimation in virtual environments. However, our result does not speak to other VR outcomes such as presence, simulator sickness, etc. As we are interested in understanding how humans perceive realistic VEs, in an effort to help bridge the gap between VR and the real world, we plan on shifting our efforts to understand how varying FoV influences these other subjective outcomes and how FoV combined with 3D stereo and motion parallax affects the distance perception in VR.

References

[1] S. H. Creem-Regehr, P. Willemsen, A. A. Gooch, and W. B. Thompson. The influence of restricted viewing conditions on egocentric distance perception: Implications for real and virtual indoor environments. *Perception*, 34(2):191–204, 2005.

[2] J. A. Jones, J. E. Swan, G. Singh, E. Kolstad, and S. R. Ellis. The effects of virtual reality, augmented reality, and motion parallax on egocentric depth perception. In *Proceedings of the 5th Symposium on Applied Perception in Graphics and Visualization*, APGV '08, p. 9–14, 2008. doi: 10.1145/1394281.1394283

[3] J. W. Kelly, L. A. Cherep, and Z. D. Siegel. Perceived space in the htc vive. *ACM Trans. Appl. Percept.*, 15(1), July 2017. doi: 10.1145/3106155

[4] J. M. Knapp and J. M. Loomis. Limited field of view of head-mounted displays is not the cause of distance underestimation in virtual environments. *Presence: Teleoperators & Virtual Environments*, 13(5):572–577, 2004.

[5] S. Masnadi, B. Williamson, A. N. V. González, and J. J. LaViola. Vriassist: An eye-tracked virtual reality low vision assistance tool. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pp. 808–809, 2020.

[6] K. Pfeil, S. Masnadi, J. Belga, J.-V. Sera-Josef, and J. LaViola. Distance perception with a video see-through head-mounted display. In *To appear in Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 2021.

[7] R. S. Renner, B. M. Velichkovsky, and J. R. Helmert. The perception of egocentric distances in virtual environments - a review. *ACM Comput. Surv.*, 46(2), Dec. 2013. doi: 10.1145/2543581.2543590

[8] C. S. Sahm, S. H. Creem-Regehr, W. B. Thompson, and P. Willemsen. Throwing versus walking as indicators of distance perception in similar real and virtual environments. *ACM Trans. Appl. Percept.*, 2(1):35–45, Jan. 2005. doi: 10.1145/1048687.1048690

[9] P. Willemsen, M. B. Colton, S. H. Creem-Regehr, and W. B. Thompson. The effects of head-mounted display mechanical properties and field of view on distance judgments in virtual environments. *ACM Trans. Appl. Percept.*, 6(2), Mar. 2009. doi: 10.1145/1498700.1498702

[10] Y. Zhao, E. Cutrell, C. Holz, M. R. Morris, E. Ofek, and A. D. Wilson. Seeingvr: A set of tools to make virtual reality more accessible to people with low vision. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, pp. 1–14, 2019.