Distance perception in NPR immersive virtual environments, revisited

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Distance Perception in NPR Immersive Virtual Environments, Revisited

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Abstract

Non-photorealistic rendering (NPR) is a representational technique that allows communicating the essence of a design while giving the viewer the sense that the design is open to change. Our research aims to address the question of how to effectively use non-photorealistic rendering in immersive virtual environments to enable the intuitive exploration of early architectural design concepts at full scale. Previous studies have shown that people typically underestimate egocentric distances in immersive virtual environments, regardless of rendering style, although we have recently found that distance estimation errors are minimized in the special case that the virtual environment is a high-fidelity replica of a real environment that the viewer is presently in or has recently been in. In this paper we re-examine the impact of rendering style on distance perception accuracy in this virtual environments context. Specifically, we report the results of an experiment that seeks to assess the accuracy with which people judge distances in a non-photorealistically rendered virtual environment that is a directly-derived stylistic abstraction of the actual environment that they are currently in. Our results indicate that people tend to underestimate distances to a significantly greater extent in a co-located virtual environment when it is rendered using a line-drawing style than when it is rendered using high fidelity textures derived from photographs.

CR Categories: I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism – *virtual reality.*

Keywords: Spatial perception, head mounted displays, virtual environments, non-photorealistic rendering.

1 Introduction and Previous Work

Immersive virtual environments technology has tremendous potential to enhance the process of architectural design by offering architects and their clients the ability to experience designed structures from a full-scale, first person perspective before they are built. However, virtual walkthroughs have traditionally focused on featuring fully finished models in as realistic a manner as possible, and have therefore typically been reserved for use during the latest stages of the design process, after all of the critical design decisions have already been tentatively made. Our research aims to explore the potential for using virtual environments technology to facilitate architects' ability to investigate a wider range of alternative conceptual approaches to a design earlier on in the design process.

Strothotte *et al.* [1994] identify non-photorealistic rendering (NPR) as a more promising technique than realistic rendering for conveying a sense of uncertainty or incompleteness about an initial architectural design. A study by Schumann *et al.* [1996] found that when an architectural model is rendered in a sketch-like, hand-drawn style, viewers are more likely to interpret the design as unfinished and more willing to offer critique or suggestions for change. Klein *et al.* [2000] presented a method for rendering a virtual environment in a painterly style using stroke-based textures, and many other real time NPR techniques also have the potential to be successfully used in a virtual environments context.

One of the primary motivations for using virtual reality to display architectural models at full scale is to enable viewers to achieve an accurate, intuitive understanding of the sense of the space defined by the design [Henry and Furness 1993]. To this end, we need to understand the affordances and limitations of using abstraction in virtual reality. Previous studies have found that people tend to underestimate distance in virtual environments under a wide variety of conditions. To what extent can we effectively immerse people in a non-photorealistic representation of an environment, and still enable them to interpret the environment as if they were really there?

Several researchers have studied distance perception in NPR virtual environments. Gooch and Willemsen [2002] compared distance perception in real and non-photorealistically rendered virtual environments using blind walking, and found that participants significantly underestimated distances in the non-photorealistic virtual environment relative to in the real world. Thompson *et al.* [2004] compared participants' distance perception in a real environment and three virtual representations of the same environment: a high-resolution photographic panorama, a low quality textured computer graphics rendering, and a wire frame rendering. They found significant distance compression in each of the virtual environments, but did not find significant differences in the magnitude of participants' errors between the virtual environment rendering conditions.

In recent studies ([Interrante *et al.* 2006] and [Interrante *et al.* 2008]), we have discovered that people tend *not* to seriously underestimate distances in a virtual environment that is a faithfully-sized, high-fidelity replica of the actual real environment they are concurrently occupying. In this paper, we seek to determine whether people will retain the ability to make accurate judgments of distance in a virtual environment that replicates their concurrently occupied real environment in a less realistic, more abstract style.

2 Experiment

The goal of our experiment was to assess participants' ability to accurately estimate distances in a non-photorealistically rendered version of our laboratory, and to compare these results to the results of our previous experiments ([Interrante *et al.* 2006 and 2008]), in which we assessed participants' distance perception accuracy in a high fidelity virtual model of the same room.

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2.1 Method

In order to ensure comparability between the results of our present and previous experiments, we took great pains to use the same experimental methodology, apparatus and procedure; the only thing that changed between these two studies was the rendering style used. As in our previous experiment, we used direct blind walking to assess participants' judgments of the locations of targets placed on the floor in front of them at randomly defined distances away. Similarly, we again used written instructions to ensure consistency in the presentation of information and instructions to all participants. As in our previous study, participants were informed that the purpose of the study was to "investigate possible factors influencing distance perception in immersive virtual environments", however in this study they were explicitly told that they would be immersed in a virtual environment that was a "non-photorealistically rendered" replica of the same room that they were presently in, while in the earlier study the instructions referred to the virtual environment as a "high fidelity" replica. No training was done and no feedback was given at any time during the experiment.

2.2 Apparatus

The experiment was conducted in the Digital Design Consortium laboratory at the University of Minnesota. The lab includes a large open space with a rear-projected curved screen along one side. The size of the open space is 30' long x 25' wide at its widest point, tapering down to 16.5' wide at each end. As in our previous experiment, the virtual environment was modeled as a texture mapped set of polygons. However for this experiment we replaced the original textures, which had been created from photographs of the interior of the lab, with line drawings created by tracing over the original textures with solid black lines. For the wall and ceiling textures, we drew the lines at the locations of the principal edges in the image; on the floor, we replaced the tiled carpet texture with a rectangular grid of lines. Our intent was to emulate the style of the wireframe virtual environments used in the Gooch and Willemsen [2002] and Thompson *et al.* [2004] studies, although those environments were rendered from the contours of geometric objects, not from textures. As in our previous studies, the real lab contained furniture and computers along some of the walls that was not included in the model. Earlier testing [Interrante *et al.* 2008] has found no effect on users' distance estimation errors of the presence vs. absence of rendered furniture. Figure 1 shows an image of the original high fidelity virtual environment and figure 2 shows the non-photorealistically rendered virtual environment from the same viewpoint. Both images are rendered with barrel distortion to correct for the pincushion distortion introduced by the head mounted display.

The virtual environment was presented using an nVisor SX head mounted display manufactured by nVis, which offers a separate 1280 x 1024 image to each eye, spanning a manufacturer-specified 60º monocular field of view with 100% stereo overlap. Foam blinders attached to the HMD blocked peripheral vision of the external environment. The device weighed approximately 1 kg. and was connected to a video control unit (VCU) by a 15' cable. The VCU was mounted on a wheeled cart, allowing the participant free access to anywhere in the room. An assistant was present during the experiment to manage the cables and the cart and to prevent the weight of the cables from exerting any forces on the participant's head. The viewpoint used for image generation was determined in real time from data provided at 1000 Hz by a HiBall 3000 optical ceiling tracker manufactured by 3rd Tech.

Figure 1: A screen capture of the high-fidelity virtual environment used in our earlier experiment [Interrante *et al.* 2008].

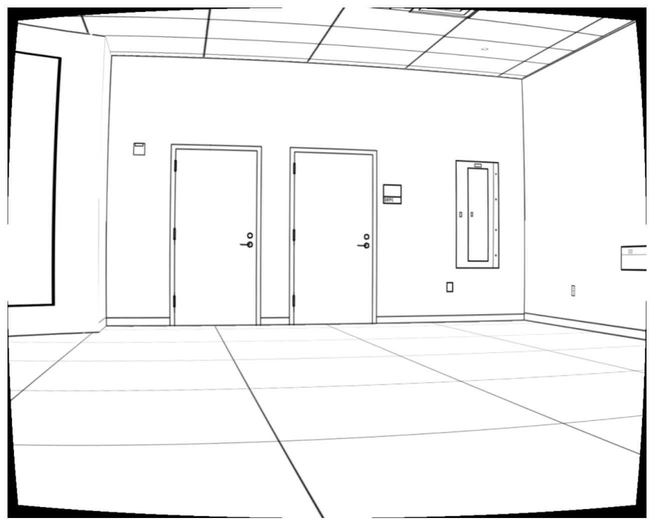

Figure 2: A screen capture of the same model rendered in a non-photorealistic style.

2.3 Participants

We recruited eight participants for this study from passersby in front of the building housing our lab. All participants were students at the University of Minnesota, ranging in age from about 20 to 30 years old, and none had previously participated in our earlier studies. Participants were compensated for their time with a $10 gift card to a local retail store.

2.4 Procedure

After entering the lab and signing the consent form, participants were asked to read the written instructions describing the experiment. They were then assisted in putting on the head mounted display before beginning the first trial. To mask any ambient sounds that could potentially be used for positioning, participants were also required to wear a portable radio with miniature earphones that played static noise. Each participant was asked to perform 20 blind walking trials in the virtual environment, followed by 10 trials in the real environment.

At the beginning of each of the VE trials, the software would place a virtual piece of tape on the floor at a random distance 8'-22' in front of the participant. Distances were automatically clamped so that the tape mark was always at least two meters away from any wall. Participants were instructed to look at the tape mark and then when they were ready to make a distance judgment, to say 'ready', close their eyes and walk until they felt they had reached the tape mark, and then to say 'done'. When the participant said 'ready' the display was set to black and their initial location was recorded. When they said 'done', both their ending location and the actual location of the target were recorded. With his or her eyes still closed, the participant was then guided by the experimenter to an arbitrary new position in the room. As an added precaution, the display was not turned back on until the participant was ready to begin the next trial. One researcher worked at the keyboard to record positions and control the display, while the other managed the cables and directed the participant to the starting location of the next trial.

In the real environment, participants wore a blindfold instead of the HMD and the experimenter had to randomly place two cloth strips to mark the initial and target positions for each trial. Participants were not allowed to see the markers being taken up or placed down. At the end of each trial, the researchers would use a tape measure to determine the distance between the starting and ending cloth strips as well as the distance between the starting cloth strip and the participant's final position, before repositioning the marks and leading the participant, still blindfolded, to his new starting position. Because this manual measuring process took longer than the computerized measuring process used in the VE trials, we opted to require fewer real world than VE trials in order to keep the approximate time participants spent in each phase of the experiment the same.

2.5 Results

Figure 3 shows the raw results from our current experiment, color-coded by participant, and figure 4 shows the raw results from our earlier experiment for comparison. The filled dots indicate judgments made in the virtual world and the hollow dots indicate judgments made in the real world. From these raw point plots one can already see that there are noticeable differences in the results between the two rendering conditions. To clarify the results presentation, we prepared the graphs shown in figures 5 and 6, which plot, for each participant, the average relative error (computed as (walked_distance–actual_distance)/actual distance) in their real world distance judgments along the horizontal axis and the average relative error in their VE distance judgments along the vertical axis. When participants make similar errors in both the real and virtual environments, the points will fall near the diagonal. The results of the ANOVA tests for significance in the difference between the real world and virtual world errors for each participant are conveyed by the color coding of the dots in these charts. Fully colored (green or blue) dots indicate results that were strongly significantly different between the real and virtual world conditions ($p<0.01$), light grey dots indicate results that were only moderately significantly different ($p<0.05$), and white dots indicate results that were not significantly different ($p>0.05$). In figure 6, most of the dots are near the diagonal and are colored white, indicating that participants seem to judge distances with equivalent accuracy in our real lab and in a high fidelity virtual model of a our lab, experienced as a co-located VE. In figure 5, however, all of the dots appear below the line, and fully colored, indicating that participants consistently underestimated distances in the NPR virtual environment relative to in the real world.

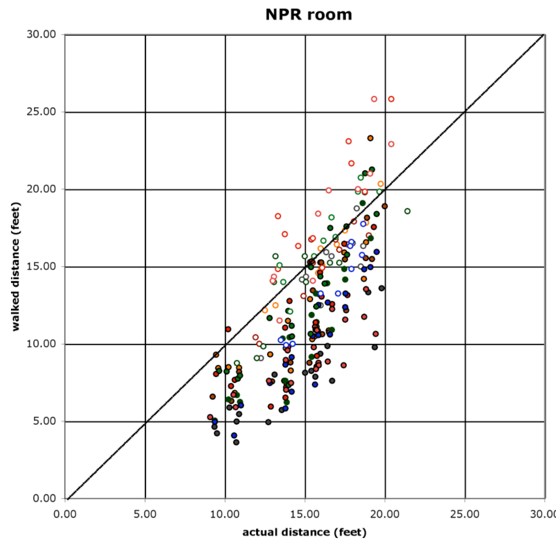

Figure 3: Raw results from our current experiment. Hollow dots indicate judgments made in the real world and filled dots indicate judgments made in the virtual environment.

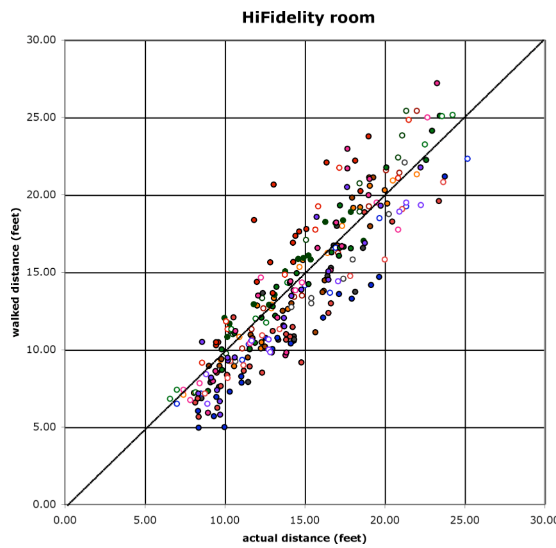

Figure 4: A plot of the raw results from our earlier experiments.

We also ran an ANOVA comparing the magnitude of the difference in the real and virtual world errors made by the participants who experienced the NPR virtual environment with the real-virtual world errors made by participants who experienced the high fidelity VE. This ANOVA is based on 8 participants in the NPR case and 10 in the high-fidelity case, and it indicates that the differences between these two rendering conditions are significant $\{F(1,16) = 30.60;\ p < 0.001\}$.

3 Discussion

The combined results of our present and previous experiments elaborate upon the findings reported by Thompson *et al.* [2004] to enable a more nuanced understanding of the impact of rendering style on the accuracy of participants' distance judgments in a presented virtual environment. Specifically, they suggest that the quality of the representation of a virtual environment *does* matter in some situations.

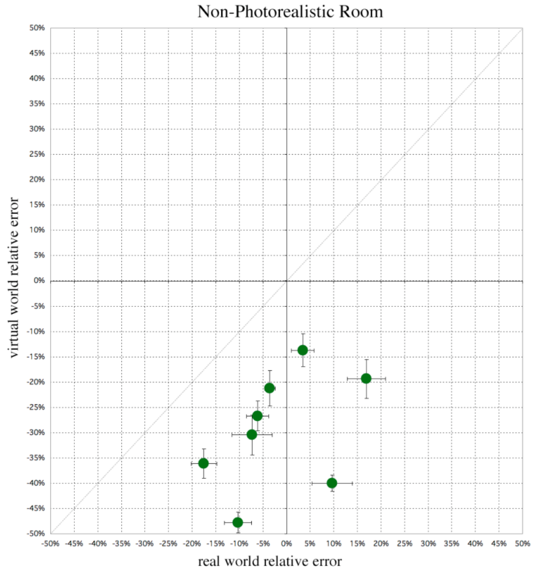

Figure 5: A plot of the results from our current experiment.

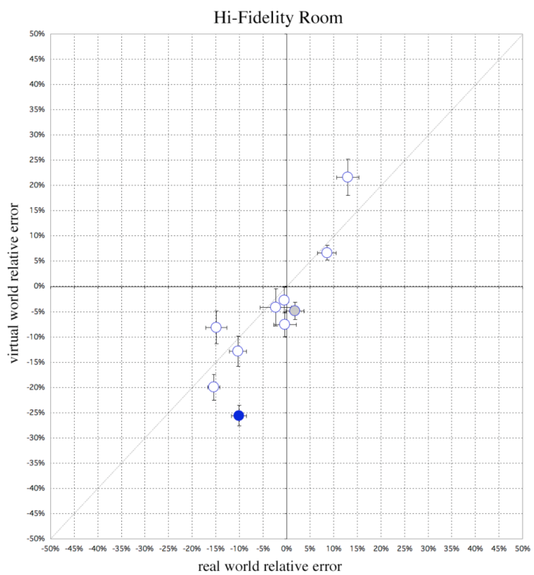

Figure 6: A plot of the results from our two earlier experiments.

One possible explanation for our findings is that our non-photorealistic textures simply lack sufficient detail to enable an accurate assessment of distance information. However this explanation would be inconsistent with the results of Thompson *et al.* [2004] who found that the level of detail in the graphics, by itself, does not appear to have a significant impact on distance judgment accuracy. It is likewise possible that the geometrical simplicity of our model is a complicating factor. We have informally observed that, in the HMD, the NPR room appears noticeably flat, as if the architectural details were simply drawn onto featureless white walls. Although photorealistic textures are also purely 2D, and were applied to the same flat walls, the impression of flatness in that environment is not as striking.

An alternative explanation for our findings is that the unrealistic nature of the non-photorealistic representation interferes with participants' presence in the VE, compromising their ability to suspend disbelief and interpret that what they are seeing through the head mounted display as if it were a reliable representation of what they would be seeing if the virtual world were actually real.

4 Future Work

In future work, we intend to more directly explore the question of presence in NPR virtual environments. We also plan to investigate potential methods for enabling more accurate distance perception in NPR immersive virtual environments, such as providing people with an avatar self-embodiment [cf. Ries *et al.* 2008] in the NPR VE or by employing alternative NPR textures, including textures whose statistics more closely match the statistics of peoples' typical visual input in the real world.

Acknowledgments

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