Measuring Virtual Object Location with X-Ray Vision at Action Space Distances

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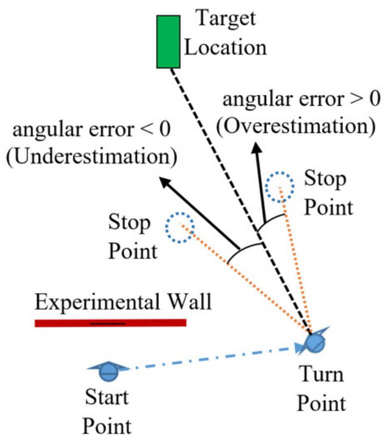
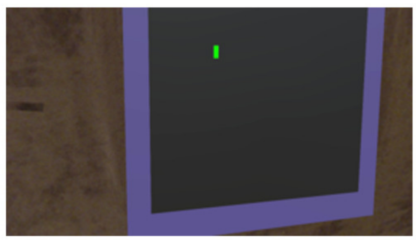


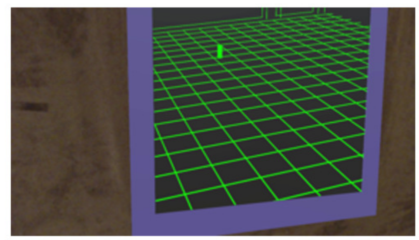
(a) Triangulation by walking method in x-ray vision

(b) Viewing through real window

(c) Viewing through opaque wall



(d) Viewing through virtual window



(e) Viewing with virtual window and background

Figure 1: Experimental methodology. The triangulation by walking task (a) is performed for each condition: opaque wall (b), virtual window (c), and virtual window and background (d).

Abstract

Accurate and usable x-ray vision is a significant goal in augmented reality (AR) development. X-ray vision, or the ability to comprehend location and object information when it is presented through an opaque barrier, needs to successfully convey scene information to be a viable use case for AR. Further, this investigation should be performed in an ecologically valid context in order to best test x-ray vision. This research seeks to experimentally evaluate the perceived object location of stimuli presented with x-ray vision, as compared to real-world perceived object location through a window, at action space distances of 1.5 to 15 meters.

1 Introduction

In AR x-ray vision, operators are able to see beyond opaque surfaces that would normally occlude their view to content presented beyond those surfaces. Most typically, this has been envisioned in the form of an operator observing the interior of a room from outside or a surgeon seeing through a patient's skin to the scanned data underneath, but there are a range of applications in industry, design, and tactical displays, among others. Many of these tasks require mobility and local exploration, which places them within the purview of *action space distances*. These distances range from 1.5 to 30 meters and are the distances over which an operator might visualize an immediate intended action. In x-ray vision tasks, then, a successful mobile application would need to accurately convey perceptual information at action-space distances.

Of course, it is important to clarify exactly what perceptual information x-ray vision is conveying to an operator. In projecting scene information, x-ray vision can present a large spectrum of stimuli, objects, and events to operators, and various facets of the understanding of this information could be experimentally analyzed. However, for this research, the focus is on a more basic understanding of x-ray vision *perceived object location*. This perceptual variable, which is composed of perceived heading and perceived distance, is the key factor in visual perception; this is how humans create an understanding of their environment. In the context of AR applications, a primary variable of interest is perceived distance. Perceived heading is another important component of perceived object location.

Visually directed actions in x-ray vision face an important obstacle: the presence of a wall or other occluding surface in front of an operator. In order to test typical x-ray vision, there must be a solid surface in front of the operator; for several visually directed actions, such as direct walking, this represents an insurmountable problem. As such, triangulation by walking is used as it is a validated experimental measure, and it allows participants to walk around the occluding wall (Figure 1a) [2]. In the context of this experimental

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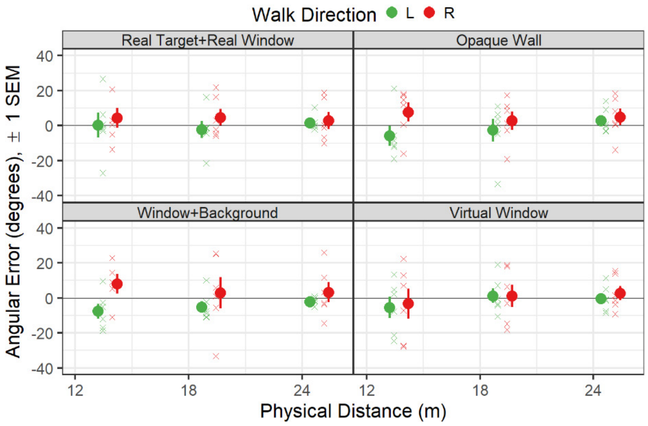

Figure 2: Preliminary experimental results for 4 viewing conditions: real target seen through a real window; x-ray vision through an opaque wall; x-ray vision through a virtual window onto a virtual background; and x-ray vision through a virtual window.

task, the scene presented focuses on a single virtual object, presented at several distances: a green cylinder, approximately the shape of a standard US soft drink container but slightly taller. This allows for participants to focus on location estimations to the cylinder instead of its relationship to other objects in the environment.

In evaluating x-ray vision, it is important to understand system effectiveness in an ecologically valid context and with the nearest possible point of comparison. As such, *visually directed actions* are used. These are actions where visual information is used to plan and direct the action and are representative of tasks that would be well-trained and ecologically valid in humans. Using a visually directed action to measure the variable of perceived object location is also thought to have the benefit of reducing the effects of cognition on judgments, reducing or eliminating its potential as a confound for the experimental methodology [1]. Further, in order to counteract the effect of handedness on the results, left and right walks are both tested. The context of these experiments is also important. There are no natural situations where humans observe environmental information through a solid, opaque wall—but the nearest ecologically valid substitute, viewing an object through a window, represents a useful model for x-ray vision.

Previous research has shown that using a window or cutaway visualization for x-ray vision can improve depth accuracy, as compared to opaque viewing [3]. It is not completely certain, but it seems likely the *window metaphor* does this by implying a context and environment that operators implicitly understand through their own prior experience (Figure 1d). It highlights extra information, with borders around the presented stimuli that might also increase depth judgment accuracy. While this technique has been previously researched, other methods in x-ray vision including background visualization have not been. It is possible that a visualization using a simple background rendering could significantly alter perceived depth perception. Further, there is relatively little research directly investigating depth perception in x-ray vision. As such, experimentally testing and comparing these x-ray vision visualization methods in a triangulation by walking task will contribute both quantitative measures of effectiveness and an examination of whether these visualizations improve the effectiveness of AR x-ray vision.

2 Experimental Methodology

The purpose of the experimental task is to estimate perceived 3D location at action space distances. Participants observed a virtual target (shaped like an extra-tall, bright green soft drink can) located 4.18, 5.85, or 7.59 meters away across a large (5.795 m by 7.93 m) indoor room (Figure 1). Participants observed this target through a window in a cloth wall and while facing obliquely away from the target, while an experimenter in another room walked them through task execution. This cloth wall was mobile and so could be moved, allowing for walks to the left and walks to the right. Participants were instructed to observe the target and fix its location in their mind before closing their eyes and walking forward. At a certain point along their walk, they were instructed to stop and turn towards where they believed the target to be. At this juncture, there would be a short pause while an experimenter placed a bean bag directly behind their center of mass, evenly spaced between their two feet standing still. Participants were then instructed to walk confidently forward for several more steps before being halted again, and having another bean bag placed behind their feet. Participants were then led, with their eyes still closed, back towards their starting point. When they were reasonably close to it, they were instructed to open their eyes and resume standing at the starting point, facing away from the experimental field, until the next task was ready. During this brief intermission, the experimenter measured the positions of the start point and the stop point.

This experiment contained three independent variables: *target location* (4.18, 5.85, and 7.59 meters), *walking direction* (left and right), and *viewing condition* (real target through a real window; virtual target through an opaque wall; virtual target through a virtual window; virtual target through a virtual window with a virtual background). In this context, the first condition (real target through a real window) represents the control condition for the experiment; perceived object location in a real environment is expected to be quite accurate. Note that two other viewing conditions through an open window were also a part of the experimental protocol; these are not presented here but were a part of the experiment. Target location was randomized, and the presented order of walking direction and viewing condition were counter-balanced.

3 Experimental Results

Preliminary results (with 6 participants) comparing x-ray visualization types are presented in Figure 2. Of the tested comparisons, only walking direction appears to have a significant impact, but, with continued testing, more clarity is expected of the underlying distribution. The significance of walking direction on perceived object location may be related to handedness in some way; it seems reasonable that participants may be more practiced turning or walking in one direction than another, though further research is necessary to validate this conjecture. At this stage, further testing must be done to fully evaluate the relative effectiveness of each visualization methodology and to provide a quantitative measure of the overall effectiveness of x-ray vision.

Acknowledgments

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