An X-Ray Vision System for Situation Awareness in Action Space

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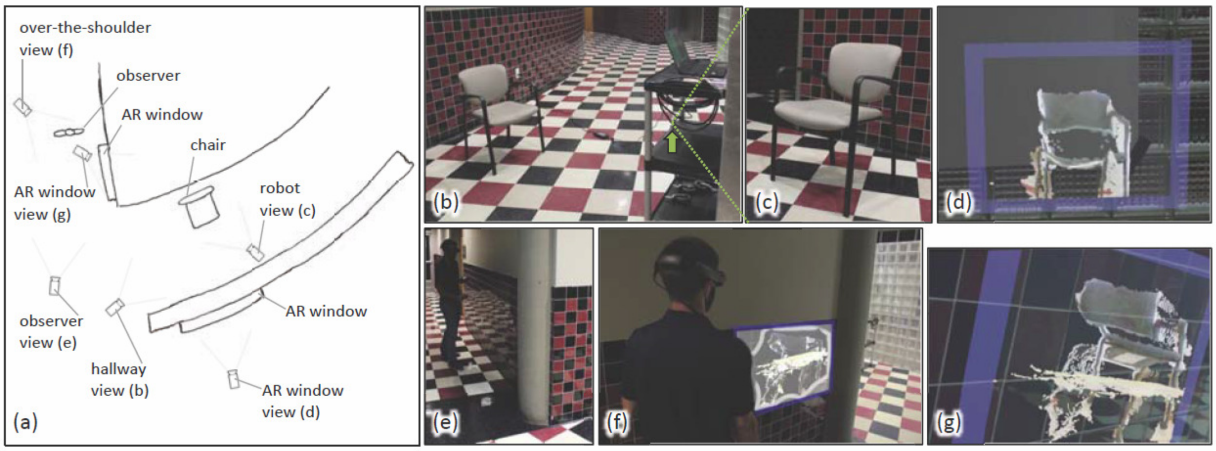

Figure 1: Overview (a) and photos from the x-ray vision system for situation awareness in action space. A stereoscopic depth camera, mounted on a robot, is oriented toward a chair (b, c), and allows an observer around the corner to see the chair through the wall (e, f). Various other AR window positions (d, g) help express the flexibility of this system and drive home how the position of the chair is communicated through walking and movement. (When these photos were taken the robot was not present).

ABSTRACT

Usable x-ray vision has long been a goal in augmented reality research and development. *X-ray vision*, or the ability to view and understand information presented through an opaque barrier, would be imminently useful across a variety of domains. Unfortunately, however, the effect of x-ray vision on *situation awareness*, an operator's understanding of a task or environment, has not been significantly studied. This is an important question; if x-ray vision does not increase situation awareness, of what use is it? Thus, we have developed an *x-ray vision system*, in order to investigate situation awareness in the context of action space distances.

Index Terms: augmented reality—situation awareness—x-ray vision—depth cues;

1 INTRODUCTION

X-Ray vision is a classical problem in augmented reality, with research focusing on many different technical aspects of the issue [1, 2, 6]. However, even across the expansive array of research, there seems to be relatively little focus on situation awareness—the key component of system effectiveness in many domains!

Defined loosely, *situation awareness* is an operator's ability to assess and evaluate the relevant variables in a given task (Figure 2); in other words, the effect of x-ray vision on situation awareness determines how effectively it extends operator perception [5]. Now, this isn't as straightforward as might be initially assumed; more information does not necessarily equate to improved situation awareness. It is entirely possible to overwhelm an operator with too much information, such that critical information becomes buried, or detract from an operator's ability to evaluate the situation, by introducing too much additional complexity. Particularly when dealing with vision and depth perception, already dense and information-rich modalities, it is arguable that x-ray vision could fall into either of those extremes, actively reducing situation awareness.

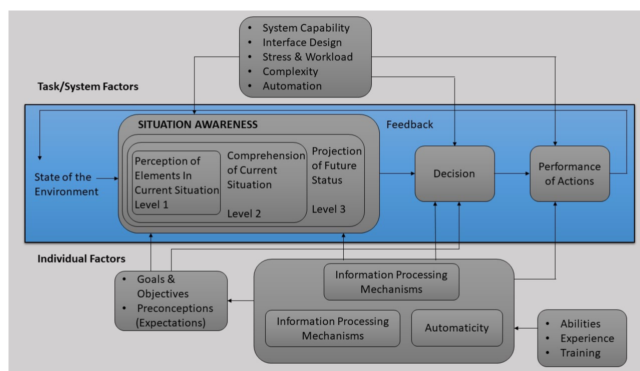

Figure 2: Situation awareness model for dynamic decision making [5].

As such, we have developed an initial x-ray vision system, for use in indoor environments at *action space* distances of $\sim$2 to $\sim$30 meters [4]. The system is part of a larger robotic platform, where a robot with a mounted depth camera navigates an indoor environment, and displays the 3D room information from the perspective of a nearby observer (Figure 2a). The robotic system's purpose is to extend operator awareness. This system gives us a stable, modern platform for performing experiments on situation awareness and

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depth perception, with respect to x-ray vision, and will allow us to consider and evaluate differing approaches to x-ray vision.

2 X-Ray Vision System

The *X-Ray Vision System* (XRS) is composed of a Magic Leap AR headset, a stereo depth camera, and a tracking fiducial. This system allows the user to place a virtual window (that is, content presented in augmented reality and not existing in the real world) through which room content can be seen and understood (Figure 1). The resulting depth information, both from the window itself and from the depth information beyond, affords a variety of depth cues for interpreting the data. Thus, the XRS is expected to improve situation awareness by supporting egocentric depth perception in a minimalist approach that incorporates and exploits several of these depth cues, along with other features.

The human visual system uses several attributes, known as depth cues, to calculate the depth of objects in view. These depth cues are wide-ranging and varied, allowing us to have accurate egocentric depth perception out to far distances [4]. However, here we will focus primarily on the depth cues relevant for this application, i.e. action space depth cues. The most important depth cues at these distances (from 2 to 30 meters) include occlusion, height in the visual field, binocular disparity, motion parallax, and relative size [4].

Of these depth cues, occlusion is perhaps the most salient [4]. This makes a lot of sense in our context; after all, it is uncommon for humans to be able to see through opaque walls. A confounding occlusion cue has been known to disrupt depth perception and increase uncertainty in augmented reality, particularly when virtual objects are near the depth of the occluding surface [1]. To prevent depth uncertainty and mis-estimations (which can be expected to degrade operator certainty and performance in some applications), we make use of a *window metaphor* (Figure 1) [2]. This metaphor piggybacks off of our ingrained understanding of windows to help provide context for x-ray vision. In practice (and as yet without any experimental evidence), this feature helps to reduce confusion and depth uncertainty for objects visualized using x-ray vision.

There are a couple of other depth cues that are important to mention for this application. First, binocular disparity, here, plays an important and variable role [4]. At distances closer to an operator, binocular disparity is expected to play a particularly significant role—but this importance decreases the farther out virtual objects are displayed. On average, we would expect binocular disparity to be a notable depth cue, but not as dominating as it would be for depth perception at reaching distances. Motion parallax is also important to mention; at these distances, it is a very salient depth cue and is observably crucial to accurate and usable x-ray vision [4]. In the context of the application, these two cues are primary drivers of depth perception, particularly as height in the visual field will likely prove to be less reliable in this context.

These features are clearly important aspects of the XRS. However, it is important to note that, thus far, most of these features have more to do with depth perception than with situation awareness, per se. How then are depth perception and situation awareness connected? Is there a good reason to consider x-ray vision in terms of situation awareness, as opposed to just depth perception?

3 Depth Perception and Situation Awareness

To answer these questions, it is important to go back to the definition of situation awareness. Classically, situation awareness is defined as a construct with three distinct levels: perception, comprehension, and projection (Figure 2) [5]. Each level is supported by the level before it; projection builds off of comprehension, which in turn relies on accurate perception. Perceptual location acts on the most basic of these levels, and thus informs and supports the other components of situation awareness.

As such, situation awareness and depth perception are undoubtedly linked, for certain tasks. These might include robotic operations and navigation, surveillance and response to an active shooter situation, or even highly demanding telepresence or oversight applications. Each of these tasks requires a certain threshold of perceptual accuracy before x-ray vision would even be usable, and, further, task performance and situation awareness may also be sensitive to minor perturbations in depth perception accuracy.

4 Situation Awareness Tests

As such, this brings us to our primary question: How are we able to test and evaluate the impact of the XRS on situation awareness?

At a very high level, we are interested both in the impact of x-ray vision on depth perception (testable by any of a number of simple open-loop tasks) and the impact of x-ray vision on the higher orders of situation awareness: comprehension and projection [7]. In order to evaluate this, we intend to measure the cognitive demand of x-ray vision using a detection response task. Cognitive demand represents the resources required to make sense of the presented stimuli—resources that then can not be used to comprehend and project a response to the observed environment. *Detection response tasks* measure this variable by presenting an aural, visual, or tactile stimulus which the operator must respond to, typically with a button press [3]. The speed and accuracy of this response, as compared to the operator's baseline, allows us to understand the impact x-ray vision has on an operator's higher-level situation awareness.

As such, we propose combining an open-loop depth perception task with a detection response task, yielding an approach that can be used to evaluate both simultaneously. With such an approach, we intend to evaluate the X-Ray Vision System and determine whether it (a) supports accurate situation awareness and (b) does so at any significant cost to higher-level situation awareness.

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