# Visualizing Occluded Physical Objects in Unfamiliar Outdoor Augmented Reality Environments


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## Abstract

This paper describes techniques to allow both the visualization of hidden objects, and removal of real objects, for a mobile augmented reality user. A gesture based technique is also described which allows the user to select when to view occluded objects. By using the real-time modeling techniques of the Tinmith system, the user is able to create the required geometry to allow image based rendering techniques to be used to render corrected images on the user's display. The images of the hidden objects are captured by a mobile robot platform that is controlled by the mobile user.



**CR Categories and Subject Descriptors:** I.3.6 [Computer Graphics]: Methodology and Techniques – Interaction Techniques; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism – Virtual Reality; J.9.e [Mobile Applications]: Wearable computers and body area networks.

**Additional Keywords:** Outdoor Augmented Reality, Wearable Computers, Telepresence, Image-based Rendering, 3D Modeling.


## 1 Introduction

Augmented reality allows a user to see their real surroundings combined with computer generated images and 3D models registered to the world. AR systems are limited however to only being able to explore and examine an environment that is visible to the user and not occluded by other objects. The system developed by Kameda *et al.* [1] allows a user to see beyond their physical surroundings and view surveillance camera images from occluded locations, rendered on their current view. This system and others like it [2], rely on the use of a pre-built geometric model of the environment. The models have to be built prior to operating the system, usually making use of a third party application and scanning hardware. This requirement makes such systems unsuitable for deployment into unexplored environments.

This paper presents a system that allows a user to explore outdoor environments using a mobile augmented reality system, while simultaneously being able to observe live video information from other physical locations. This system overcomes the problem of requiring an existing geometric model, and also demonstrates some unique visualization techniques for viewing remote video data.

In order to capture video data from remote locations we have made use of a mobile robot platform equipped with a camera. The user wears a belt-mounted wearable computer with a HMD and uses on-screen menus selected with pinch-gloves to control and communicate with the robot. The robot can be navigated to a remote location, and the video images are transmitted back to the wearable computer where they can be rendered to the display.

To overcome the requirement of an existing model of the environment, we propose that it be modeled in-situ using the modeling capabilities of the Tinmith system [3]. Tinmith was created to allow a user to model both existing objects and to create new unique geometry while outdoors. The user makes use of tracked pinch-gloves to interact with the system, and utilizes construction tools such as moving, scaling and rotating pre-defined shapes, or creating buildings by defining planes for each wall. The visualization techniques presented in this paper have been integrated into the Tinmith modeling system, allowing the user access to the full range of its modeling capabilities.

## 2 Visualization

In order to allow the user to see what the robot sees, while it is out of view of the user, we provide a picture-in-picture display on the screen. This live video stream can be seen rendered in the bottom corner of the display in Figure 1. This visualization is useful for simple navigation, but does not provide the user with any intuitive clues as to the location of the information shown on the display. The techniques presented in this section make use of this same video data, but use different rendering techniques to make them appear corrected for the user's current viewpoint.

This simple overlay view mode is also used to allow the user to operate in an optional remote telepresence mode. The image is rendered as the background image on the display, and the user's location in the virtual world is updated to be that of the robot. This means that with the exception of head and position tracking, the user gains the full benefits of having physically moved to the

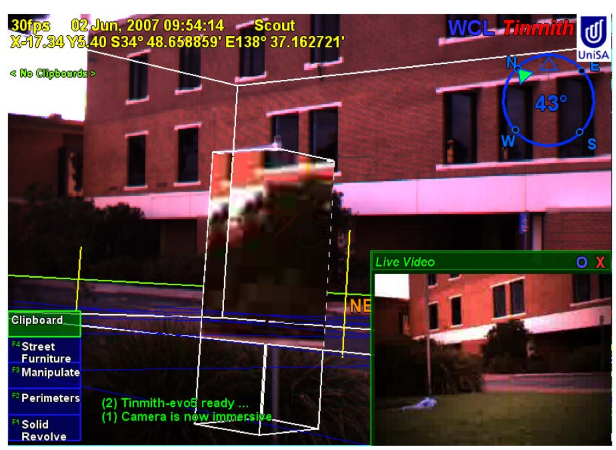


Figure 1 – A street sign is made to disappear by rendering over it on the display. The remote video is shown Picture-in-Picture


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Figure 2 - Two handed magic-lens allows the user to see 'through' buildings

remote location. The full set of modelling techniques afforded by Tinmith can still be used, which allows the user to create geometry at a remote location, or simply from another viewpoint nearby to their current physical location. A typical use-case for this system might be in a disaster recovery scenario; the user can control the robot to move to an unsafe location, or one inaccessible to the AR user. Then using a combination of the telepresence mode, and the normal immersive AR mode, they can construct approximate models of the key features they need to observe.

The system could also be easily extended to support multiple robots, or even the ability to possess the viewpoint of another user wearing an AR system.

### 2.1 Visualizing Occluded Objects

Without a geometric model of a scene, it is not possible to render an image from a camera that aligns with the real world on a display at a different location. Once the system has a simple geometric model of an object, it is possible to correctly render textures onto the objects directly from a video stream. This is done by rendering the 3D model of the occluded object to the display, then projective texturing it with the camera image from the appropriate location [2]. Due to the use of photorealistic textures, the models can be simple approximations of the objects without much noticeable loss in quality.

Occluded objects cannot be rendered directly on the user's display otherwise they cause abnormal depth cues to the user, and restrict the view of their physical surroundings. Previous work [1] overlaid occluded objects semi-transparently on the display, however in an immersive AR situation it is important not to clutter the display. We chose to use a magic-lens [4] style technique to let the user choose when to display this hidden information. The user can use their hands to drag out a rectangular area in front of them, inside of which the previously hidden information is rendered. This gives the impression that the user is 'tearing' a hole through one building to see the other. Figure 2 demonstrates the user using this magic-lens interface to view an occluded building.

### 2.2 Making objects disappear

The other technique that this system affords is the ability to make an object 'disappear'. When a physical object visible to the user obstructs the view of a scene behind it, it is possible to make the object appear to have disappeared by drawing an appropriate overlay on top of it. The overlay is the view the user would see if the occluding object was not there. In the example shown in Figure 1, a street sign is made to disappear by drawing part of the building behind it to the display.

In order to select a real-world object to remove, the user places a 3D model at the position of the object. The model does not need to be an accurate reconstruction of the object, but simply needs to cover its whole area. The 3D model of the environment is then used as a 2D mask to define where on the display to render the object behind it. This technique requires that the scene behind the object be modeled in order to correctly render the occluded scene on the display.

## 3 Implementation

The hardware implementation of this system consists of two main components, the mobile robot, and the Tinmith mobile computer, which are linked together via an 802.11 wireless network. The software is built on the Tinmith software architecture.

The robot platform is based on an electric wheelchair equipped with typical outdoor AR components: laptop computer, GPS receiver, camera and orientation sensor. The laptop communicates to a custom microcontroller board which operates the motor controllers and ensures the motors stop moving if the computer or software crashes. The wearable computer we use is the custom built belt-mounted wearable Tinmith AR system, consisting of a similar set of components, with a HMD, and wireless pinch-gloves.

## 4 Conclusion and Future Work

We have presented a system capable of allowing a user to view occluded real-world objects in unfamiliar environments. Unlike other systems that only work in areas with existing 3D models, ours allows the user to deploy into unknown surroundings and use a gesture based interface to model the required geometry. The system only requires simple, approximate geometry to achieve acceptable results. The user is able to navigate a mobile robot to remote locations to collect the desired video images. They can then utilize a range of visualization techniques for viewing the live video data, including picture-in-picture, immersive view, viewing occluded real objects, and the ability to make physical objects disappear. A two-handed magic-lens style interface is used to select when the user wishes to view occluded objects.

In the future we plan to extend the system to support multiple robots, and to implement a real-time strategy game style control metaphor to allow the AR user to better control the movement and waypoints of the robots.

## References


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