Real-Time Gaze Mapping in Virtual Environments

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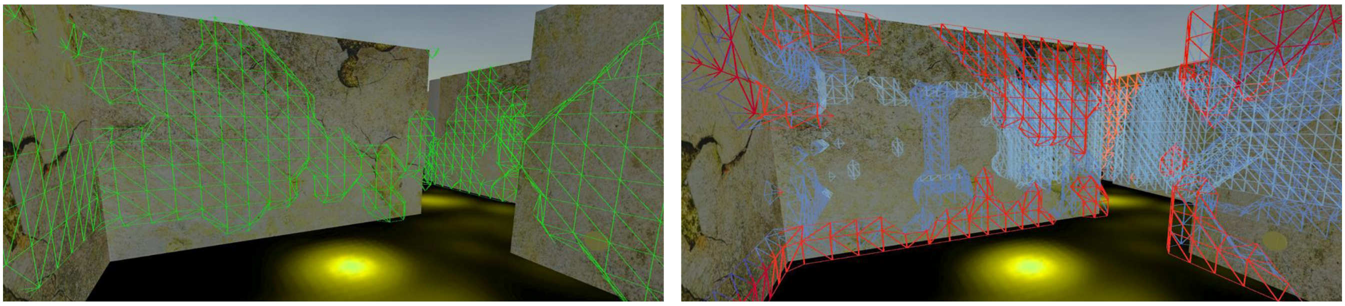

Figure 1: *All surfaces in the virtual environment are enwrapped with a grid structure. The resulting network tracks the user's gaze behavior and allows to display areas inspected by the user in green (left), as well as areas that have not been observed yet in red (right). As depicted on the right, it is also possible to display not inspected, occluded areas in different shades of blue (dark to light corresponds to close to far). A heat map on the ground additionally supports the user by tracking his or her (physical) body movements in the virtual environment.*

Abstract

In order to analyze an analyst's behavior in an immersive environment, his or her eye movements can be monitored using eye trackers. Hereby, points of individual interest can be objectively identified, for instance, to assess the usability and intuitiveness of a framework. However, this technique can be used not only as a post-event analysis tool but also to assist an ongoing exploration of a virtual environment. With this poster, we present a technique that allows a real-time gaze map creation which supports the immersed analyst by providing real-time feedback on the user's own activity. In our approach, all surfaces in the virtual environment are enwrapped with a mesh structure. The grid structure recognizes when a user drifts with his or her eyes above it and increments weights of activated node points. This allows highlighting areas that have been observed, but also those that have not been observed - also when they are occluded by other objects or surfaces. We tested our technique in a preliminary qualitative expert study and received helpful feedback for further improvements.

CCS Concepts

• ***Human-centered computing*** → ***Virtual reality;*** • ***General and reference*** → *Design;*

1. Introduction

A gaze map is a cumulative representation of a user's gazes that can be gathered using eye trackers. In literature, gaze maps are also referred to as 'attention maps', 'heat maps' or 'fixation maps'. In the past, researchers frequently used them for interface design studies, for instance, to investigate a user's viewing behavior on web pages [PHG*04, BCM09]. However, they were also deployed in various types of 3D environments. For example, they were used in real environments to investigate users' points of regard [Pfe12] or in virtual reality environments (VREs) to examine students in plane inspection training sessions [DSR*00]. Blascheck et al. [BKR*14] provide an overview of different visualization techniques for eye tracking data.
In this manuscript, we present an approach that allows to track a user's gaze behavior in real time. Our proposed technique can be used as a supporting tool for the analyst in an immersive environment to identify unnoticed areas without overplotting the investigated space. This can help users in immersive analytics environments keep track of their actions and could improve the orientation capabilities of users. In addition, we can make use of the applied grid structure to highlight uninspected, occluded areas with different colors. We created an initial prototype that is capable of tracking a user's gazes and movements in a VRE. We experimented with different representations and conducted a qualitative pilot user study.

2. Gaze Mapping with See-Through Option

All monitored surfaces are covered by a network of cube skeletons. This creates a uniform grid structure and an addressable front face

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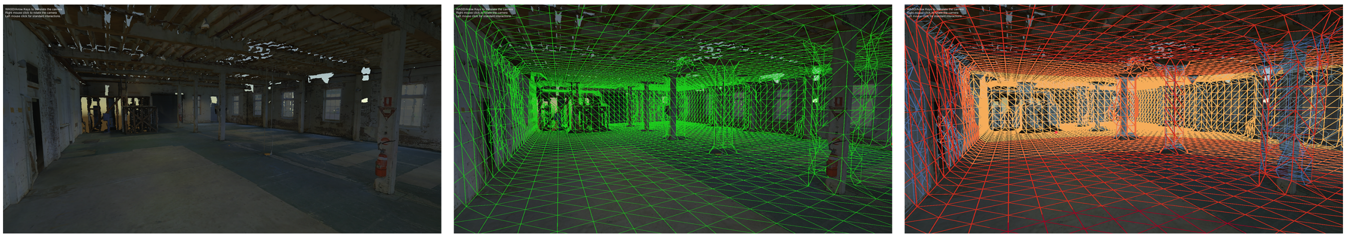

Figure 2: *The virtual environment (left) is enwrapped with a grid structure (center). Each joint in this structure is capable of counting how often a user's gaze rested on it. Depending on the number of gazes for a section, segments can be faded in or out or dyed in a certain color. As shown on the right, user-centered, stepwise colorscales can be used to serve as additional depth cues. As can also be seen on the right, it is also possible to insert the grid structure of occluded surfaces (blue grid).*

and back face for each surface. Colliders on each joint of this network are triggered if they collide with the transmitted focal point of the eye tracker. We deployed an adaption of the marching cube algorithm [LC87] to trigger and activate areas in the grid structure that are touched by a user's gaze. For each section in the network, a gaze counter is incremented with each activation, making it possible to visualize how often the user's eyes focused on a certain area. To allow the analyst to still see the underlying surface, we solely display the sparse grid structure instead of overplotting as it is common practice for heat maps. In our prototype, it is possible to either focus on observed areas (activated parts of the grid; Fig. 1 left) or display areas that have not been considered (Fig. 1 right). Simple parametrization can be used to determine which threshold to take for treating a joint in the network as "observed" or "not observed". If the threshold is set on 1, areas in the grid structure are displayed in the gaze map as soon as the user's gaze touched it briefly, even if the user did not rest his eyes on that area. By default, the grid structure is hidden and can be displayed on demand. The complete prototype is publicly accessible via GitHub (`https://github.com/hanibalv2/Real-time_gaze_mapper_vr`). We used an HTC Vive Pro [Viv] in combination with a PupilLabs Eye-Tracker [Pup].

As depicted in Fig. 2, our basic approach allows to display a grid structure of all visible surfaces that have not yet been inspected by the user (center). We extended that view by inserting the grid structures of occluded surfaces in different colors (Fig. 2, right). This leads to a see-through effect, drawing the user's attention to surfaces that have not been inspected and are not visible from the current perspective. As depicted in Fig. 2 (right), it is possible to combine two different color scales: One encoding visible surfaces (red) and the other occluded ones (blue), while both gradually describe the distance to the observer (step-wise transitions with shades of red/blue).

3. Qualitative User Study

In an initial qualitative user study, 11 participants tested our prototype and provided us with feedback. For the study, we created a maze-like environment with five rooms (see Figure 3). We randomly placed eight markers on the walls and asked participants to find each marker while being allowed to use all tools. This comprised the following options: Users could walk around and teleport unrestrictedly and visually inspect all the walls in the VRE. Moreover, they were able to display and hide a heat map on the floor reflecting their history of movements in the virtual space. They were also able to fade in a live-updating gaze map that displayed which surfaces they have inspected by covering them in a grid structure (see Fig. 1, left). Additionally, they could insert a gaze map that displayed all areas not considered. Last but not least, they were able to activate the see-through option, showing not observed, occluded surfaces in shades of blue (see Fig. 1, right).

As a result of this pilot study, we received positive feedback regarding the improvement of orientation and the ability of the tool to make the user aware of unnoticed areas. In addition to questions about the general usability and intuitiveness of the deployed functions, we asked the participants for their subjective assessment of the usefulness and applicability of our gaze map in immersive analytics scenarios. Among other things, the see-through option (n = 4), the reflection of inspected areas with the provided grid highlighting (n = 4), and a therewith connected improved search efficiency (n = 3) were evaluated as helpful. Four participants also claimed that the installed functions (in particular the gaze map and movement heat map) had improved their orientation in the VRE.

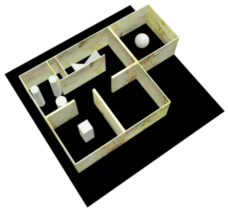

Figure 3: *Test environment for the qualitative user study. Participants were asked to find all randomly placed disc-sized markers in the scene, being allowed to use both the gaze- and the heat map.*

4. Future Work

We are currently working on using this technique in an immersive analytics application. Moreover, we are planning on re-implementing different existing techniques like volume gaze mapping with particle systems in order to evaluate various techniques in a quantitative user study.

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