Gaze-directed Immersive Visualization of Scientific Ensembles

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Abstract

The latest advances in head-mounted displays (HMDs) for augmented reality (AR) and mixed reality (MR) have produced commercialized devices that are gradually accepted by the public. These HMDs are generally equipped with head tracking, which provides an excellent input to explore immersive visualization and interaction techniques for various AR/MR applications. This paper explores the head tracking function on the latest Microsoft HoloLens – where *gaze* is defined as the ray starting at the head location and points forward. We present a gaze-directed visualization approach to study ensembles of 2D oil spill simulations in mixed reality. Our approach allows users to place an ensemble as an image stack in a real environment and explore the ensemble with gaze tracking. The prototype system demonstrates the challenges and promising effects of gaze-based interaction in the state-of-the-art mixed reality.

Author Keywords

Immersive visualization; gaze-directed interaction; scientific ensembles.

ACM Classification Keywords

I.3.6 [Computer Graphics]: Methodology and Techniques - Interaction Techniques; H.5.1 [Information interfaces and presentation]: Multimedia Information Systems - Artificial, Augmented, and Virtual Realities;

Introduction

With the advances of the latest technologies in HMDs, gaze tracking becomes easily available in many commercialized affordable devices, making the approaches of gaze tracking applicable to a wide range of applications. Gaze tracking is also expected to become an important component of immersive visualization and analytics, which is proposed to use new interaction and display technologies to support analytical reasoning and decision making [5]. This project proposes to explore gaze tracking for immersive visualization towards the goals of developing effective visualization systems and enhancing user experiences.

We should clarify that the term "gaze tracking" is loosely defined for the latest devices. For the Microsoft HoloLens, the *gaze vector* is defined as the ray starting at the head position and pointing towards the head's forward direction. This is different from the traditional eye tracking which utilizes the user's eye movements to determine focus points or regions of interest. Not only HoloLens, the majority of the latest HMDs provide head tracking instead of eye tracking. During the past years, both the eye tracking and head tracking have been studied in research and they are considered the easiest alternative interface methods [3, 1].

This project studies a gaze-directed immersive visualization system in mixed reality using Microsoft HoloLens. We work on an important scientific application that involves of image ensembles, which requires the visualization and comparison of a set of images. We have developed a prototype system that visualizes a set of images by placing them in a real environment and allows a user to use gaze to interact with the images. Our initial results demonstrate the effects of gaze-based interaction approaches for immersive visualization and provide a platform to improve the interaction and perform evaluations.

The remainder of this paper is organized as follows. We first summarize the related work of gaze tracking. We then describes our gaze-based visualization approach of simulation ensembles in the mixed reality and present example results and discussions. Finally, we conclude and provide the future work of gaze-based immersive visualization.

Related Work

As the gaze tracking in mixed reality is related to both eye tracking and head tracking, this section summarizes the related work from these two aspects.

During the past decade, the field of eye tracking has received much attention from researchers [3]. Eye tracking approaches has been used in a variety of visualization applications, including volume visualization [15], scientific visualization, software visualization [10], text visualization [2], etc. Many approaches represent the spatial coordinates of fixations and saccades [16], and fixations are often used to analyze areas of interests. There is a special focus on analyzing gaze data to compute a map of visual saliency for both 2D images [7] and 3D objects [13, 11]. The 3D gaze fixations are often achieved based on the intersection of objects and eye directions. The eye tracking approach has also been explored for mobile devices [17] and virtual environments [14, 9]. Instead of requiring eye tracking devices, regions or objects-of-interests were measured by both bottom-up (stimulus-driven) and top-down (goal-directed) aspects [14, 9].

The increased popularity of head tracking has been shown in a number of applications, such as assistive technology, teleconferencing, virtual and mixed reality. Similar to eye tracking, approaches of head tracking can be categorized to image-based, sensor-based, and device-based approaches. For example, Al-Rahayfeh and Faezipour presented a state-of-art survey for eye tracking and head movement detection methods [1]. Zapala and Balaj presented a case study of eye tracking and head tracking in assistive technologies for patients [18]. The comparison results showed that both tracking methods can be used for entertainment and communication, with the performance of head tracking lightly faster.

Gaze-directed Immersive Visualization

We use a visualization project of simulation ensembles to demonstrate gaze-tracking in mixed reality. The simulation ensembles are time-series 2D images generated by coupled SWAN + ADCIRC model on a high-resolution computational mesh [8]. They were used to forecast the oil transport in the nearshore after the destruction of the Deepwater Horizon drilling platform during the spring of 2010. The SWAN + ADCIRC simulations account for the influence of tides, riverine discharge, winds and wind-driven waves.

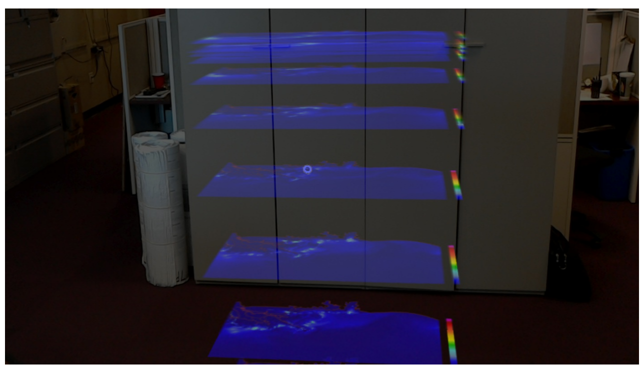

Figure 1: Example immersive visualization of the simulation ensemble in mixed reality. Gaze location is computed with our approach and shown as the cursor. The distances between adjacent images are automatically determined by the gaze location.

We first present our visualization approach for simulation ensembles in mixed reality, which utilizes the large spaces in a real physical environment. The basic design is to have an image ensemble visualized as an image stack in the middle of the room. By default, the stack is about 1.5 meters in height, and the images are distributed at equal vertical distances in the stack. During user interaction, images closer to the gaze point are spread apart vertically for the user to focus on a single image, while further images are pushed closer together, as shown in Figure 1. This allows the user to quickly scan through the images by simply looking up and down. The user can easily observe details in an image they are interested in and make comparisons.

One key issue of gaze-directed immersive visualization is determining the user's center of attention, or the gaze point. For HoloLens, the gaze point on a simple surface is computed with a ray cast using the gaze vector and identified by the closest hit point. In our case, however, there are multiple overlapping surfaces, and they are constantly moving based on the user's gaze vector. Using a simple ray cast may cause the images to move erratically in an unpredictable way. Instead, we consider the gaze point to be the closest point on the vertical axis of the stack image stack to the gaze vector. The gaze point, $T(s_c)$, is derived from the parametric equation to find the shortest line segment between two lines in space (figure 2). Let T_0 be the center of the image stack, $\vec{u}$ the vertical unit vector, C_0 the location of the user, and $\vec{v}$ the user's forward unit vector. The gaze point is $T(s_c) = T_0 + s_c\vec{u}$. The parameter s_c for the gaze point on the vertical image-stack axis is computed as follows:

$$s_c = \frac{be - cd}{ac - b^2} \quad \text{where} \quad \begin{aligned} a &= \vec{u}.\vec{u}, \\ b &= \vec{u}.\vec{v}, \\ c &= \vec{v}.\vec{v}, \\ d &= \vec{u}.\vec{w_0}, \\ e &= \vec{v}.\vec{w_0}, \\ \vec{w_0} &= T_0 - C_0 \end{aligned}$$

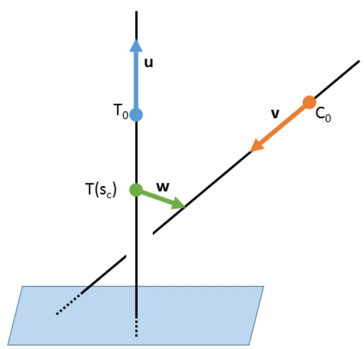

Figure 2: Computation of the gaze point. The 3D vectors of u and v do not intersect in the space generally.

For each image in the ensemble set, the vertical distance from the gaze point is computed, and that image is offset using the derivative of a Gaussian curve. The derivative has the greatest value in the vicinity of the gaze point, and a very low value at further distances. The derivative is also zero at the gaze point. The result is that the images around the gaze point get spread apart. Figure 3 provides an example of a zoomed in view when the user stands close to the image ensemble visualization for details.

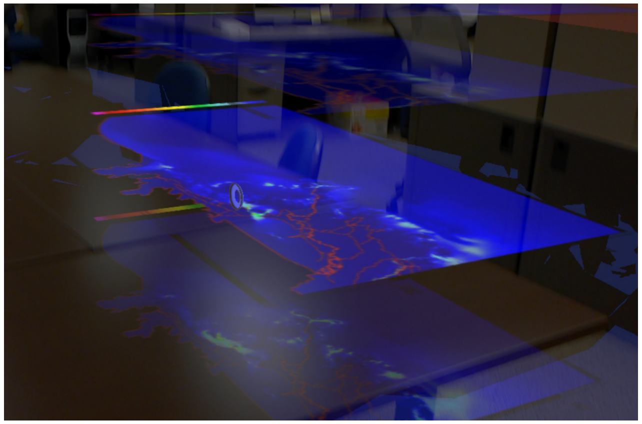

Figure 3: In the mixed reality with HoloLens, a user can walk close to the visualization and observe the details.

We have implemented our prototype system with Unity, which offers very good integration with the Hololens SDK. The image ensemble is rendered with sprites, which are quads with textures placed in the 3D space. An important limitation of our current prototype system is the data size, which restricts the number of images and the image resolutions for the textures. For interactive performance, the example snapshots in Figures 1 and 3 only use 10 textures with less than 1 megapixels each. We plan to explore other solutions of this problem.

Discussions

While immersive visualization is relatively new, a number of augmented reality systems have been evaluated and received positive results [12, 6, 4]. Throughout this project, we have explored several aspects that immersive visualization may provide advantages over desktop visualization systems:

- First, the mixed reality provides a large 3D rendering space for visualizing and organizing visual information than a desktop monitor. The space is especially useful to explore data with complex relationships, such as the geospatial and temporal relationships in a simulation ensemble.
- Second, compared to standard eye tracking devices, the HMDs for AR/MR are less intrusive. The gaze-based interaction may provide intuitive operations for users in the future immersive visualization systems.
- Third, in addition to gaze tracking, the latest technologies provide new interaction channels including speech recognition and gestures, which opens the doors for numerous new interaction techniques.

Conclusion and Future Work

Gaze tracking has become a common feature in the latest augmented and mixed reality applications. It serves as the most straightforward input provided by the HMDs for AR and MR. This project has investigated the gaze tracking in MR using the latest developer version of Microsoft HoloLens published in 2016. We have developed a prototype system for ensemble visualization and exploration in MR based on gaze tracking. Our approach visualizes the scientific ensembles as image stacks that are spread apart vertically at the user's attention point. Our results demonstrate that visual attention can be collected using the head tracking provided by HoloLens.

With the growth of immersive visualization in augmented and mixed realities, we plan to study how to measure visual attention in head or gaze tracking and feed the information to immersive visualization systems. Similar to eye tracking data, all the information collected in the AR and MR can be used to analyze user behaviors and guide visualization design. What's special with immersive visualization is that all the other information that can be collected during the interaction, such as head location and hand gestures, should be integrated to provide a fully interactive analysis environment and enhance user experiences.

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