Considerations on Binocular Mismatching in Observation-Based Diminished Reality

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ABSTRACT

In this paper, we introduce novel problems of binocular stereo (binocular mismatching) in observation-based diminished reality. To confirm these problems, we simulated an observation-based diminished reality system using a video see-through head-mounted display. We also demonstrated that simple methods can reduce such binocular mismatching.

Keywords: Diminished reality, mixed reality, video see-through head-mounted display, binocular stereo, image-based rendering.

Index Terms: H5.1 [Information interfaces and presentation]: Multimedia Information Systems - Artificial, augmented, and virtual realities.

1 INTRODUCTION

Diminished reality (DR) is a technology that mainly removes undesirable objects from a perceived environment. The visual removal technology is categorized into "inpainting-based DR (IB-DR)" that fills a target region with an apparently plausible image estimated from pixels surrounding the region, and "observation-based DR (OB-DR)" that superimposes a hidden view recovered from background observation results onto the region decided from a user-specified bounding box. In OB-DR, the main problem is how consistent the synthesized image is not only in the target region but also between the region and the surrounding. More specifically in the case using a binocular video see-through (VST) HMD, we should consider binocular mismatching due to several causes: camera calibration error, synchronization error between left and right cameras, discrepancy of the target regions, and discrepancy of synthesized hidden views.

As rendering methods for OB-DR, various approaches such as image warping [1], view-dependent texture mapping (VDTM) [2] and light field rendering (LFR) [3] are available. These methods can potentially render correct hidden views by using sufficient observation information even if the scene contains complex shapes and non-Lambertian surfaces. However, in practice, it is difficult to generate a completely consistent image because of limitations in observation of hidden areas, i.e., limitations of the number of viewpoints and illumination conditions. Inconsistent regions due to these limitations can affect binocular stereo in OB-DR. However, in most existing DR researches on either approach, there has been little discussion about what happens in OB-DR with binocular stereo through a VST-HMD.

In this study, we report two experimental results to show that there exist the following two kinds of binocular mismatching effects particularly in OB-DR:

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Perceived Depth Fluctuations: If the distribution of the pre-acquired images for hidden views is not sufficiently dense, selected viewpoint for the user's view to render the hidden view can be far from the user's viewpoint. Independently selecting source viewpoint for each eye leads to frequent temporal texture switching depending on user's viewpoint change that forces to fluctuate the perceived depth.

Bounding Box Ghost in 3D: Even if geometric consistency problem is completely solved, photometric inconsistency can reveal the hidden view window (e.g., inconsistent shades or shadows due to illumination changes can reveal the hidden view window). Since target regions of left and right eye images have disparities, the window appears in 3D. Photometric inconsistency can increase or decrease pixel values entirely; thus, photometric inconsistency further emphasizes this phenomenon while it is obvious that this can be caused by geometric inconsistency.

Our major contributions can be summarized as follows:

- We find new binocular mismatching problems specifically in OB-DR systems using binocular VST-HMD.
- We present simulated results of binocular mismatching in OB-DR as the first evidence.
- We introduce guidelines for reducing binocular mismatching in OB-DR.

2 EXPERIMENTS AND DISCUSSION

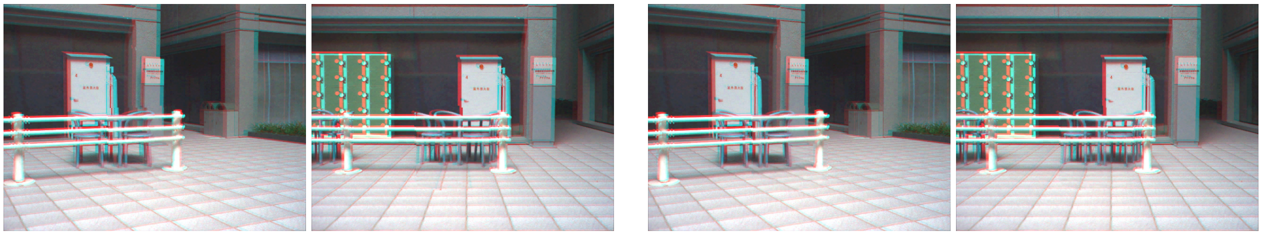
In this section, we demonstrate the above-mentioned two kinds of binocular mismatching effects by two experiments.

2.1 Experimental Setup

As an HMD, we used only displaying functions of a Canon HH-A1 where left and right eye images are displayed at 60 Hz, 1280×960 resolution with 41.0° (H) FoV. The embedded stereo displays are converged at 1.4 meter with 63 mm interocular distance. Image sequences of a 1/12 miniature studio shown in **Figure 1** were systematically shot by using an industrial 6DoF robotic arm, Denso VS-087 with a camera (Flea 3 GigE, operating at 640×480 resolution, 24-bit RGB color) and a lens with a 40.5° (H) FoV and 6.5 mm focal length. Note that the intrinsic parameters of the camera were pre-obtained and the extrinsic ones of each frame could be calculated from the arm parameters.

In the two experiments, target objects were the traffic cone and helmet as shown in Figure 1. A cylinder-shaped bounding box was placed over the target objects. Before placing the target objects, we obtained light field data LF_D in spherical coordinates system (r: 400 mm, $-2.5° \leq \varphi \leq 2.5°$, $0° \leq \theta \leq 60°$, 200 by 20 camera

Figure 1: Experimental setup in a 1/12 miniature set



(a) 10^{th} and 100^{th} frame of DR_{S-1} (b) 10^{th} and 100^{th} frame of DR_{D-1}

Figure 2: Results of Experiment 1

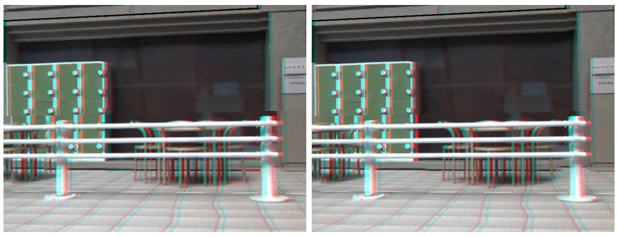


Figure 3: Stereo VDTM (left) and Cyclops VDTM (right)

Figure 4: Results of Experiment 2. 10th frame of DR_{D-2}, DR_{D-2-M}

array). Next, we created sparse light field data LF_S by thinning one image for every five ones of LF_D.

2.2 Experiment 1

This experiment shows *Perceived Depth Fluctuation* effects. For this experiment, we recorded 200 stereo images SI_1 with their extrinsic parameters. We recovered the hidden view for every stereo image of SI_1 using LF_S and LF_D, and obtained OB-DR results DR_{S-1} and DR_{D-1} respectively ("Hidden View Recovery and Composition" stage). Finally, we displayed and observed the results using the VST-HMD and compared DR_{S-1} and DR_{D-1}.

Figure 2 (a) and (b) show the 10^{th} and 100^{th} frames of DR_{D-1} and DR_{S-1}, respectively. Although these two sets of images look similar to each other at a glance, in these two frames of DR_{S-1}, there was a disparity switching around the storage and the table with chairs while such switching was not observed in DR_{D-1}. (See the figures and supplemental video through cyan-red anaglyph glasses).

Furthermore, 134 images of the LF_D were aligned using Agisoft PhotoScan and a 3D model was created manually to recover hidden views using VDTM. VDTM in stereo was accomplished using two methods of source viewpoints: "Stereo VDTM" independently chooses source images for each eye to render a stereo image [4] and "Cyclops VDTM" chooses the same images for both eyes and displays the same depth view corresponding to the center of the user's eyes to generate a stereo image. Stereo VDTM could cause *Perceived Depth Fluctuations* due to its sparsely covered view-dependent images. On the other hand, Cyclops VDTM could reduce such viewer's discomfort though the viewer could perceive the depth at a certain depth. In other words, Cyclops VDTM discarded binocular parallax but remained motion parallax. The effects are shown in **Figure 3**.

2.3 Experiment 2

In this experiment, we increased all pixel values of SI_1 by 20 and generated SI_2 to cause photometric inconsistency deliberately. Next, same as the Experiment 1, we recovered the hidden view for every stereo image of SI_2 using $LF_{D,}$ and obtained OB-DR results DR_{D-2}. In addition, we blurred the mask images to generate alpha maps to alpha blend SI_2 and recovered views smoothly. Given SI_2, the alpha maps, LF_D, we obtained OB-DR results DR_{D-2-M}. Finally, we displayed and observed the results using the VST-HMD to compare DR_{D-2} and DR_{D-2-M}.

Figure 4 shows the 10th frame of DR_{D-2} and DR_{D-2-M}. While the brightened recovered region does not stand out with naked eyes, readers may easily find the Bounding Box Ghost in 3D in DR_{D-2} with anaglyph glasses. In Figure 4 (right), the ghost effect appears inconspicuous even with anaglyph glasses.

3 Conclusion

In this paper, we showed the first evidence that binocular mismatching effects appear in OB-DR using VST-HMD. In the experiments, we presented simulated results of the effects using a photographic system in a miniature set and a binocular stereo OB-DR system that is an extended version of existing OB-DR approaches in terms of binocular stereo. Finally, we presented some guidelines for reducing binocular mismatching in OB-DR, such as Cyclops VDTM can partially solve depth perception switching and boundary blending is one possible method in reducing bounding box ghost effects in 3D. In future work, we will further investigate binocular mismatching both in OB-DR and IB-DR, and conduct statistical analysis.

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