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Computation Techniques in Tera-pixel-scale Full-parallax Computer Holography for 3D Display

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Abstract: *Tera-pixel-scale fringe images are required for creating quality CGHs that reconstruct amazing deep 3D scenes. However, it is very difficult to calculate such large-scale fringes in full-parallax. Techniques based on numerical field propagation are summarized for computing object fields by physical simulation and multi-viewpoint images.*

1. Introduction

Full-parallax computer-generated holograms (CGH) can reconstruct the ultimate 3D images, because they have no conflict among depth sensations and thus the capabilities to reconstruct amazing very deep 3D scenes that any other 3D imaging technique cannot achieve [1]. However, it is estimated that more than trillion pixels are required to produce 3D images with the same size as 40-inch HD-TVs [2]. Computation of the tera-pixel-scale (TPS) full-parallax CGHs is a challenging task in computer holography.

2. Object field based on physical simulation

The nature of a hologram is its fringe pattern generated by optical interference of an object field with a reference field. In computer holography, the object field is calculated from the 3D model like computer graphics (CG). Many researchers prefer the point-based method (point cloud) to calculate the object field. However, the point-based method is too time-consuming to calculate large-scale object field in full-parallax. Therefore, the polygon-based method, based on field propagation, is used to create sub TPS CGHs shown in Fig.1 and 2.

2.1 The polygon-based method

Figure 3 shows computation of object fields using the polygon-based method [4,5]. Polygon fields (c) are calculated from surface functions (b), defined for each polygon, using several techniques of field propagation.

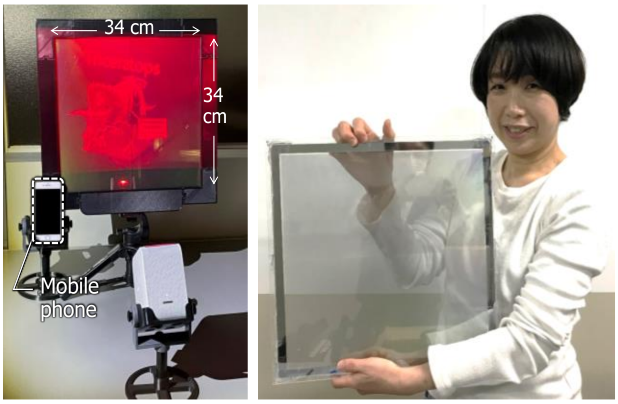

Fig. 1. Optical reconstruction of the monochrome sub TPS CGH. The fringe image is composed of 0.36 T pix.

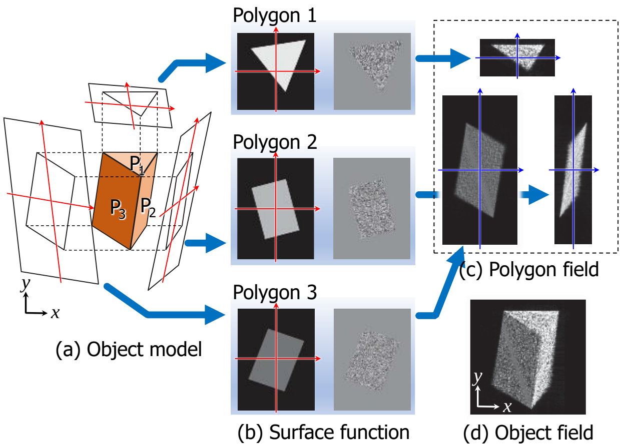

Fig. 3. Computation of object waves using the polygon-based method [5].

2.2 Numerical field propagation

Numerical field propagation is classified into three groups shown in Fig. 4. We developed the band-limited angular spectrum method [6] for parallel field propagation in (a), the rotational transform [7] for non-parallel propagation in (b), and the shifted angular spectrum method [8] for off-axis field propagation in (c).

2.3 Mask-based occlusion processing

Occlusion processing is one of the most important but most difficult computation techniques in computer holography. The visibility test is commonly used in the point-based method but is too time-consuming for large-scale CGHs. In creation of the sub TPS CGHs, a mask-

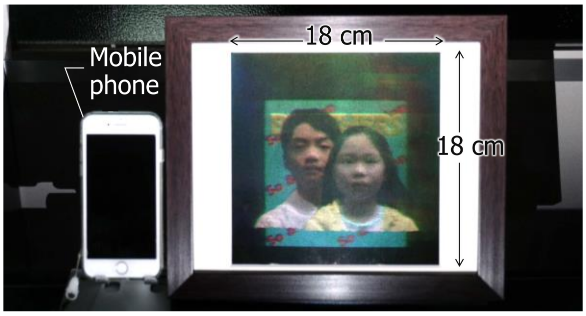

Fig. 2. Optical reconstruction of the full-color sub TPS CGH using RGB color filters [3]. The fringe image is composed of 0.1 T pix.

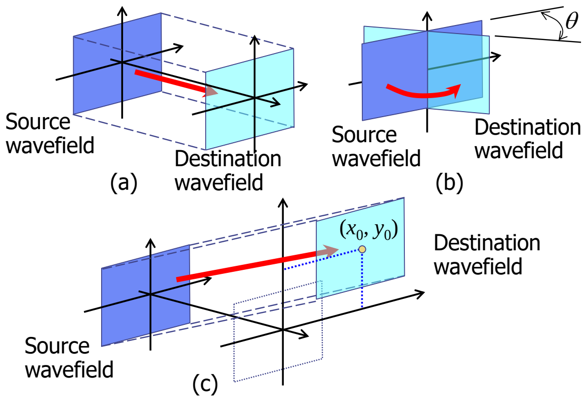

Fig. 4. Three classes of numerical field propagation used in large-scale computer holography.

based technique called the silhouette method [9] and its acceleration technique, named the switchback technique [10], are used for occlusion processing.

The switchback technique, which propagates object fields back and forth many times, has the ability to process self-occluded objects very fast when comparing the visibility test. However, because the mask is silhouette, i.e., orthographic projection of the polygon, there are gaps between masks in some cases. The gaps are sometimes perceived as cracks of the object surface in the optical reconstruction of large-scale CGHs. More exact shielding technique using surface masks and a double rotational transform is proposed to remove the cracks [11]. Optical reconstruction of a sub TPS CGH, where the exacter technique is used for occlusion processing, is shown in Fig. 5.

2.4 Rendering specular surface and transparent object

Not only diffusive surfaces but also specular surfaces can be rendered in the polygon-based method [12]. Recently, we proposed a technique to reconstruct transparent objects by physical simulation of optical refraction phenomenon [13].

3. Object field based on multi-viewpoint image

We can calculate full-parallax object fields from multi-viewpoint images (MVI). Unfortunately, image-based techniques do not give proper depth sensation by accommodation in general, and thus, cause sensational conflict in deep 3D scenes. However, since the technique of ray-sampling plane (RSP) uses field propagation [14], the technique can be used for large-scale computer holography. In this technique, we can use advanced CG rendering techniques for CGHs. Therefore, we have proposed a hybrid technique to embed an RSP-based object field in polygon-based object fields with proper occlusion processing [15].

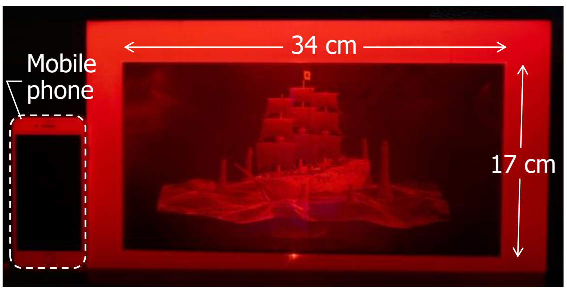

Fig. 5. Optical reconstruction of the monochrome sub TPS CGH using exacter occlusion processing. The fringe image is composed of 0.18 T pix.

4. Conclusion

Computation techniques are summarized for creating tera-pixel-scale CGHs.

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References

[1] K. Matsushima, *Introduction to Computer Holography*, Chapter 1 (Springer, 2020).

[2] K. Matsushima, H. Nishi, “Challenges to tera-pixel-scale full-parallax computer holography for 3D imaging,” Frontier in Optics + Laser Science 2022, FM5E.2 (2022).

[3] Y. Tsuchiyama, K. Matsushima, “Full-color large-scaled computer-generated holograms using RGB color filters,” Opt. Express **25**, 2016-2030 (2017).

[4] K. Matsushima: “Computer-generated holograms for three-dimensional surface objects with shade and texture,” Appl. Opt. **44**, 4607-4614 (2005).

[5] K. Matsushima, S. Nakahara, “Extremely high-definition full-parallax computer-generated hologram created by the polygon-based method,” Appl. Opt. **48**, H54-H63 (2009).

[6] K. Matsushima, T. Shimobaba, “Band-limited angular spectrum method for numerical simulation of free-space propagation in far and near fields,” Opt. Express **17**, 19662-19673 (2009).

[7] K. Matsushima, H. Schimmel, F. Wyrowski, “Fast calculation method for optical diffraction on tilted planes by use of the angular spectrum of plane waves,” J. Opt. Soc. Am. **A20**, 1755-1762 (2003).

[8] K. Matsushima, “Shifted angular spectrum method for off-axis numerical propagation,” Opt. Express **18**, 18453-18463 (2010).

[9] A. Kondoh, K Matsushima, “Hidden surface removal in full-parallax CGHs by silhouette approximation,” Syst. Comput. Jpn. **38**, 53–61 (2007)

[10] K. Matsushima, M. Nakamura, S. Nakahara, “Silhouette method for hidden surface removal in computer holography and its acceleration using the switch-back technique,” Opt. Express **22**, 24450-24465 (2014).

[11] K. Nakamoto, K. Matsushima, “Exact mask-based occlusion processing in large-scale computer holography for 3D display,” SPIE Proc. **11062**, 1106204 (2019).

[12] H. Nishi, K. Matsushima, “Rendering of specular curved objects in polygon-based computer holography,” Appl. Opt. **56**, F37-F44 (2017).

[13] H. Nishi, K. Matsushima, “Rendering of transparent objects in large-scale polygon-based computer holography,” Digital Holography and 3-D Imaging 2022, Tu1A.4 (2022).

[14] K. Wakunami, and M. Yamaguchi, “Calculation for computer generated hologram using ray-sampling plane”, Opt. Express **19**, 9086-9101 (2015).

[15] R. Katsura, K. Matsushima, “Hybrid technique of polygon-based and ray-sampling plane-based methods in full-parallax high-definition computer holography,” Digital Holography and 3-D Imaging 2022, Tu1A.5 (2022).