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Occlusion Processing in Computer Holography —With a Focus on Switch-Back Technique—

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ABSTRACT

A powerful technique called the switch-back technique is presented for occlusion processing. The technique allows us to process polygon-by-polygon light-shielding very fast. The computation times for various sizes of computer-generated holograms as well as optical reconstruction are presented for verifying the performance and validity of the technique.

1. INTRODUCTION

Occlusion is definitely the most important depth cue in computer holography as well as other types of 3D techniques such as stereoscopic and multi-viewpoint 3D images. Occlusion processing is, however, also most difficult process in computer holography, because high-quality computer-generated holograms (CGH) require very large space-band product [1].

In the point cloud techniques chosen by many researchers because of its simplicity, occlusion processing commonly results in the problem of 'the visibility test.' This is the test whether something obstructs the ray from a point source in the object surface to a sampling point in the hologram, as shown in Fig.1. However, the visibility test inevitably makes computation by the point cloud, which is known as a very time-consuming technique, even slower.

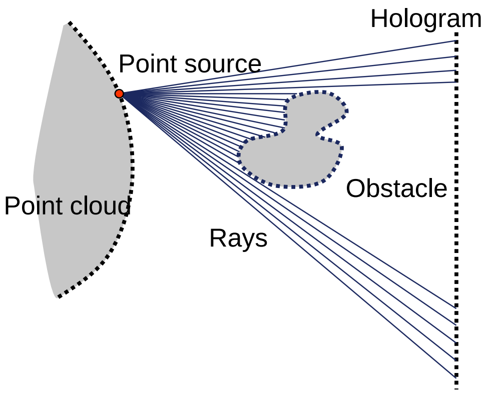

Fig. 1 The visibility test in point cloud

In the polygon-based method [2-4], mask-based techniques called the silhouette method is used for occlusion processing [5]. The silhouette method is classified into two groups; one is object-by-object (O-O) light-shielding and another is polygon-by-polygon (P-P) light shielding. Since the former is very simple and fast, O-O light-shielding is commonly used for creating high-definition CGHs which have several billions and sometimes several ten billons pixels. However, the O-O light-shielding has several drawbacks. One of them is that it is difficult and sometimes impossible to automatically determine the position of the masks. Some heuristic decision is always required for fixing the positions. This means that for the complex object model it is very difficult to simply convert the model into the CGH.

In contrast, by using the P-P light-shielding, the CGH fringe pattern can be generated from any complicated model. However, P-P light-shielding was very time-consuming because it requires the same number of field propagation as the number of polygons of the object. Recently, a novel technique called the switch-back technique is proposed for acceleration of the P-P light shielding [6].

In this article, we describe the principle and procedure

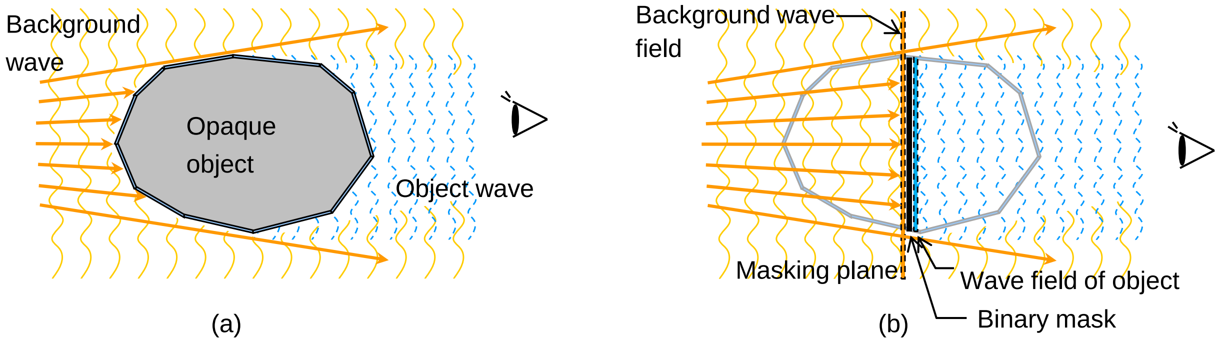

Fig. 2 The principle of silhouette-masking method [6]
(a) Light-shielding by opaque object in the real world. (b) Light-shielding simulated by silhouette-

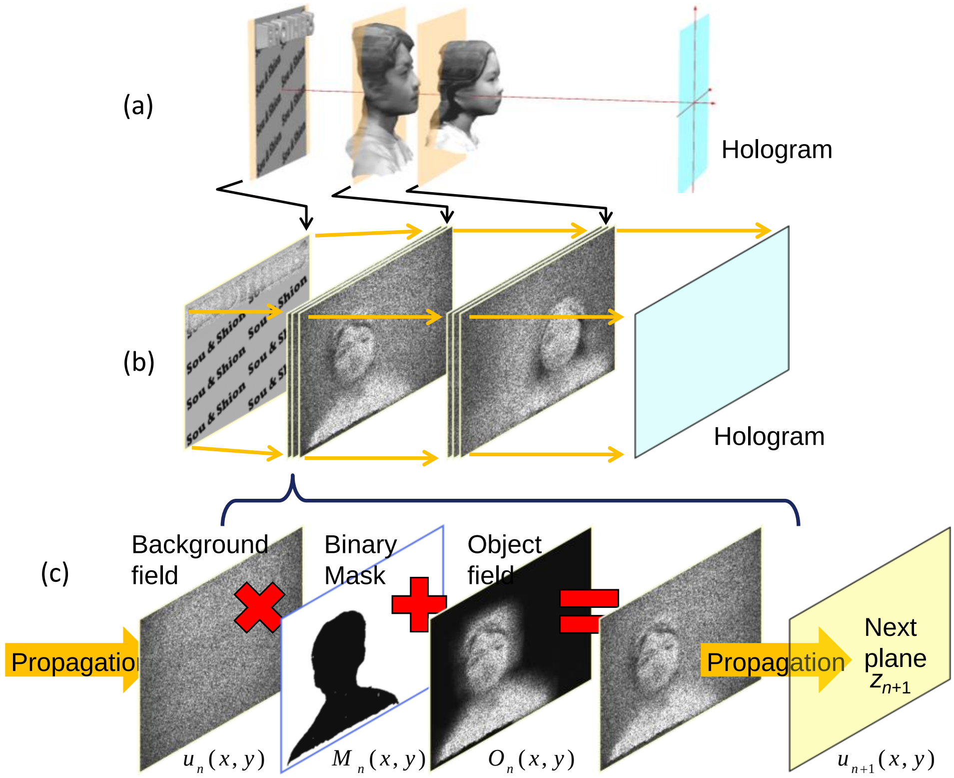

Fig. 3 The procedure for object-by-object (O-O) light-shielding [1]

(a) The 3D scene of high-definition CGH 'Brothers.' (b) Field propagation. (c) The operation in a masking plane.

of the switch-back technique. The measured performance and optical reconstruction of high-definition CGH created by using the technique is also presented in this paper.

2. TWO TYPES OF THE SILHOUETTE METHOD

2.1 Principle of silhouette-masking

Figure 2 shows the principle of the silhouette masking. Any opaque object shields the background light, as shown in Fig. 2 (a). This can be simulated by silhouette masking as in (b). In this technique, the wave field is calculated in the masking plane by using some numerical field propagation technique. The field is simply masked by a binary mask whose shape is the same as the silhouette of the obstacles.

2.2 Formulation of the procedure of O-O light-shielding for multiple objects

Figure 3 (a) shows the 3D scene of a high-definition CGH named 'Brothers' that was on display at Massachusetts Institute of Technology (MIT) Museum [7]. In this CGH, two objects are arranged in front of the background object. Thus, the field of the background object is sequentially propagated to the masking plane of the obstacles in order of depth as in (b). The procedure of the silhouette masking is given by recurrence formula as follows:

$$u_{n+1}(x,y) = \mathbf{P}_{n+1,n}\{M_n(x,y)u_n(x,y) + O_n(x,y)\}, \qquad (1)$$

where $M_n(x,y)$, $u_n(x,y)$ and $O_n(x,y)$ are the binary mask, background field and object field of the object n, respectively, as shown in Fig. 3 (c). The notation $\mathbf{P}_{n+1,n}\{\xi(x,y)\}$ stands for numerical propagation of the wave field $\xi(x,y)$ from the plane at z_n to z_{n+1}.

2.3 Drawbacks of the O-O and P-P light-shielding

If the object has complicated shape such as self-occlusion as shown in Fig. 4 (a), the object is reconstructed as a partially see-through phantom image. The viewers may also see black shadows in some cases. In addition, we cannot automatically determine the position of the masking plane.

These problems can be avoided by the polygon-by-polygon (P-P) light-shielding as in (b). The formulation and procedure of the P-P light-shielding is exactly the same as that of the O-O. The difference is that the obstacle is not an object but all polygons. However, we need many number of numerical propagation in this case. The number of propagation is actually the same as that of the polygons. This is very time-consuming especially in high-definition CGHs such as Brothers.

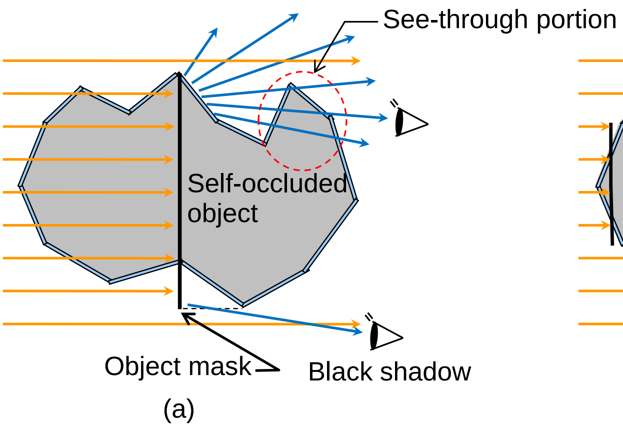

Fig. 4 Comparison between the object-by-object and polygon-by-polygon light-shielding [6]
(a) Object-by-object (O-O) light-shielding. (b) Polygon-by-polygon (P-P) light-shielding.

3. THE SWITCH-BACK TECHNIQUE

3.1 Formulation and procedure

The following simultaneous recurrence formulas can be derived from the recurrence formula of Eq. (1) after some steps [6]:

$$u_n(x,y) = \mathbf{P}_{n,\mathrm{obj}}\left\{u_n^{\mathrm{obj}}(x,y)\right\} \quad (2)$$

$$u_{n+1}^{\mathrm{obj}}(x,y) = u_n^{\mathrm{obj}}(x,y) + \mathbf{P}_{\mathrm{obj},n}\left\{O_n(x,y) - A_n(x,y)u_n(x,y)\right\} \quad (3)$$

where $u_n^{\mathrm{obj}}(x,y)$ is the temporally accumulated wave field in a plane called the object plane. The operation $\mathbf{P}_{\mathrm{obj},n}\{u_n(x,y)\}$ propagates the field $u_n(x,y)$ in z_n plane to the object plane. The operation $\mathbf{P}_{n,\mathrm{obj}}\{\xi(x,y)\}$ is the opposite. $A_n(x,y)$ is called silhouette aperture function given by simple inversion of the silhouette mask;

$$A_n(x,y) = 1 - M_n(x,y).$$

Figure 5 shows the interpretation of the simultaneous recurrence formulas of Eq. (2) and (3). Suppose that the accumulated field $u_n^{\mathrm{obj}}(x,y)$ of polygon 0 to n-1 is already calculated with P-P light-shielding in the object plane. When we add light-shielding of polygon n, (i) the field $u_n(x,y)$ in the masking plane is calculated by the backward propagation of the accumulated field $u_n^{\mathrm{obj}}(x,y)$, as in Eq. (2). And then, (ii) the field is masked by the silhouette aperture and the polygon field is added to the masked field. Finally, (ii) the field is backwardly propagate to the object plane and subtracted from the accumulated field $u_n^{\mathrm{obj}}(x,y)$, as in Eq. (3). Here, Babinet's low insures validity of the procedure.

This procedure, however, requires a double field propagation, while the original procedure needs only single propagation. The new procedure seems to be inefficient. However, let us emphasize a point; the field is required only around the silhouette aperture in the propagation in this case, as shown in Fig. 6 (b). In contrast, the original procedure always need whole field propagation as in (a). This means that the number of samplings of the field and thus the computation time can be drastically reduced in the new procedure.

3.2 Measurements of performance

The 3D scene and optical reconstruction of the test CGH are shown in Fig 7. Here, the pixel pitches of the CGH are 0.8 µm in both horizontal and vertical direction and the number of polygon of the object is 5000. The lengths indicated in (a) and

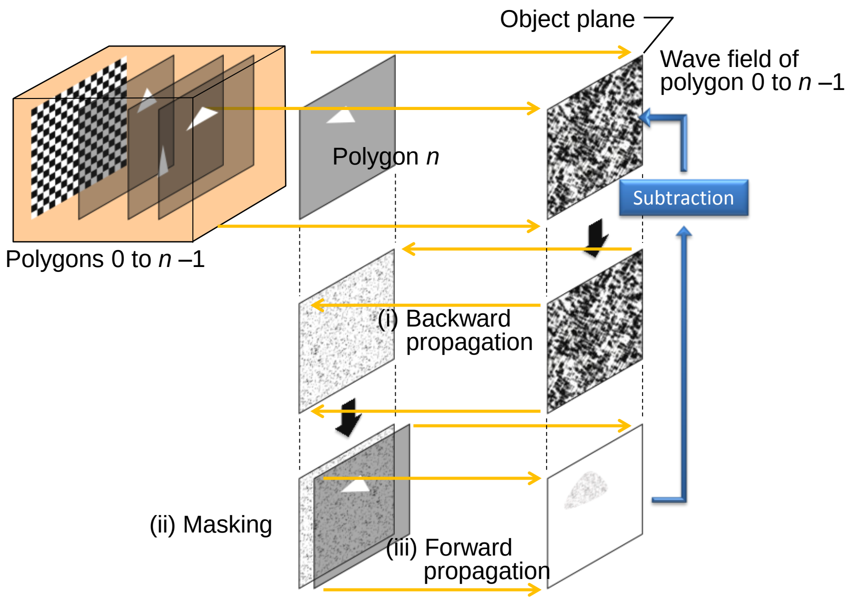

Fig. 5 The recursively defined procedure for P-P light-shielding using silhouette apertures, based on Babinet's low
The roman number indicates the order of process.

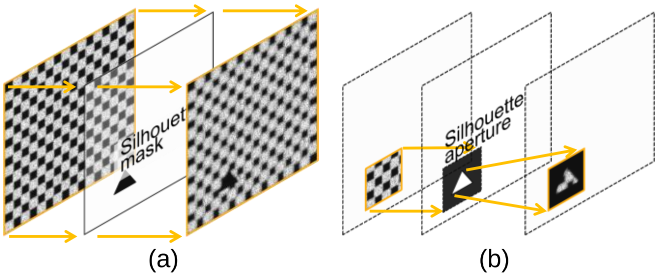

Fig. 6 Comparison between (a) silhouette mask and (b) silhouette aperture [6]

optical reconstruction is of the CGH composed of 64K × 64K pixels, where 1K =1024.

Computation times measured for various sizes of holograms are shown in Fig. 8. Here, pixel pitches are not changed in any cases, whereas the lengths indicated in Fig. 7 (a) are changed proportionally to the hologram size. The computation time increases linearly in the log scale with increasing the number of pixels. The measured maximum computation time is 1.7 hour of 64K × 64K CGH. For the 2K × 2K CGH intended to be reconstructed by electro-holography, the computation time is only 4.5 seconds. These are 20 to 60 times shorter than that of conventional P-P light-shielding [6].

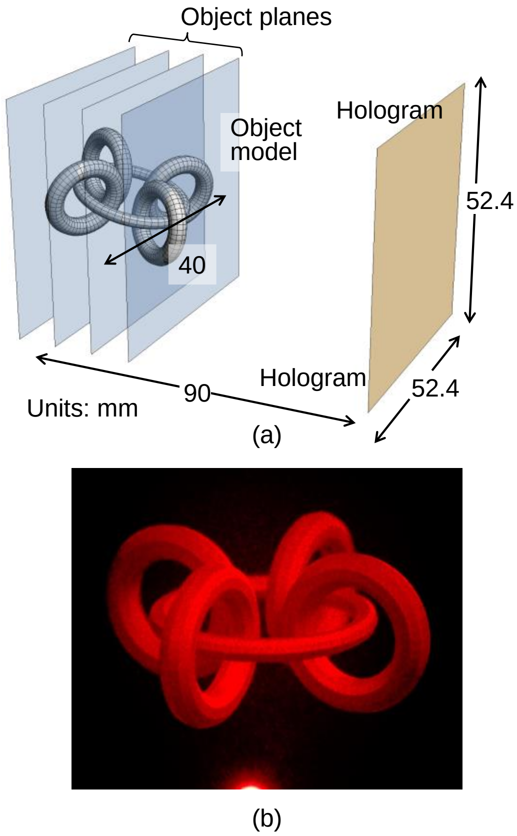

Fig. 7 The test CGH [6]
(a) The 3D scene. (b) Optical reconstruction of 64K×64K CGH.

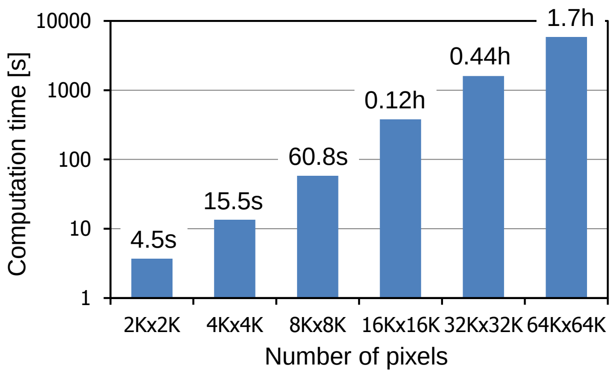

Fig. 8 Computation times of the switch-back technique for various sizes of the test CGH [6]

4. CONCLUSION

A new technique, called the switch-back technique, is presented for occlusion processing. This technique uses silhouette apertures instead of silhouette masks to reduce the number of samplings required in field propagation and accelerate computation of polygon-by-polygon light-shielding. In fact, the computation is speeded-up 20 to 60 times in comparison with the conventional technique.

ACKNOWLEDGEMENT

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