

# Rendering of Transparent Objects in Large-Scale Polygon-Based Computer Holography

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**Abstract:** A novel method for rendering transparent objects in polygon-based computer holography. The method uses rotational transform to simulate field propagation inside objects. A full-parallax large-scale CGH is demonstrated to show validity of the method. © 2022 The Authors

## 1. Introduce

Full-parallax computer-generated holograms (FP-CGH) can reconstruct 3D object without any conflicts of depth sensation, such as vergence-accommodation conflict. For the last decade, the polygon-based method [1] has successfully created large-scale FP-CGHs, composed of several tens billion or sometimes a hundred billion pixels [2]. In this technique, 3D objects formed with polygonal surfaces are reconstructed in very impressive deep 3D scenes. Not only diffusive surfaces but also specular surfaces can be rendered with smooth shading [3]. We also proposed a technique to render transparent objects [4], but the technique has two major constraints. First, the object must not have self-occlusion, i.e., concave. Second, to keep the computation time practical, the back face of the object must be a single planar polygon parallel to the hologram plane, as shown in Fig. 1 (a). We propose a new method to remove the latter restriction in this paper.

## 2. Rendering Transparent Object in Polygon-Based Method

### 2.1. Principle

As shown in Fig. 1 (b), the background field is refracted at the boundary of the back face polygon, and then propagates inside the object. The field reaching the front face polygon is refracted again at the boundary. This refraction effect can be simulated by changing the wavelength used in the numerical propagation. However, for example, the field through polygon  $\mathbf{P}_0$  is affected by all fields through the back face polygons. This means that the total number of numerical calculations needed for the whole field is given by the product of the number of the front and back face polygons. This is very time-consuming when the object is composed of many polygons.

In the new method, we divide the object at a plane, called the object plane, where the cross section takes the maximum, as shown in (c). All incident background fields are once propagated to the object plane and superposed. The field at  $\mathbf{P}_0$  is obtained from the intermediate field in this case. Thus, the total number of propagations is given by the addition of the number of the back and front face polygons, and much less than that in the case of (b).

### 2.2. Calculation of Wavefield Transmitted at Surface Boundary

The polygon-based method uses three coordinates systems: global coordinates  $(\hat{x}, \hat{y}, \hat{z})$ , parallel and tilted local coordinates  $(\hat{x}_n, \hat{y}_n, \hat{z}_n)$  and  $(x_n, y_n, z_n)$  of polygon  $\mathbf{P}_n$ , where the local coordinates share the origin. The polygon, i.e., the boundary is placed in the  $(x_n, y_n, 0)$  plane of the tilted local coordinates. Figure 2 shows the procedure for calculating the refracted light through  $\mathbf{P}_n$ .  $\lambda_0$  and  $\lambda_1$  are wavelengths outside and inside the object, respectively. The incident wavefield of  $\mathbf{P}_n$  is calculated from the background field  $f_n(\hat{x}_n, \hat{y}_n; \lambda_0)$  as follows:

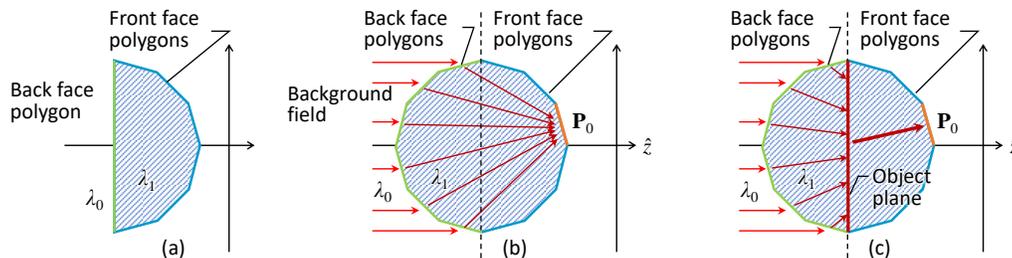


Fig. 1. The principle of simulation of field propagation inside a transparent object. (a) The limited object shape in the previous work [4]. Calculation without (b) and with (c) the intermediate object plane.

$$f_n(x_n, y_n; \lambda_0) = \mathbf{R} \{ f_n(\hat{x}_n, \hat{y}_n; \lambda_0) \}, \quad (1)$$

where  $\mathbf{R}\{\cdot\}$  represents the rotational transform of a wavefield [5], as shown in Fig. 2 (b). The wavefield in the polygon face is masked as in (c) in order to remove the field outside the polygon  $\mathbf{P}_n$  as follows:

$$f'_n(x_n, y_n; \lambda_0) = f_n(x_n, y_n; \lambda_0) A_n(x_n, y_n), \quad (2)$$

where  $A_n(x_n, y_n)$  is a binary mask function that takes 0 and 1 outside and inside  $\mathbf{P}_n$ , respectively. When the field passes the boundary, the wavelength of the wave field switches from  $\lambda_0$  to  $\lambda_1$ . The wavefield is again rotated to obtain the field in the plane parallel to the hologram, as shown in (d).

$$f'_n(\hat{x}_n, \hat{y}_n; \lambda_1) = \mathbf{R}^{-1} \{ f'_n(x_n, y_n; \lambda_1) \}, \quad (3)$$

where  $\mathbf{R}^{-1}\{\cdot\}$  is inverse rotational transform. Finally, all fields are superposed in the object plane.

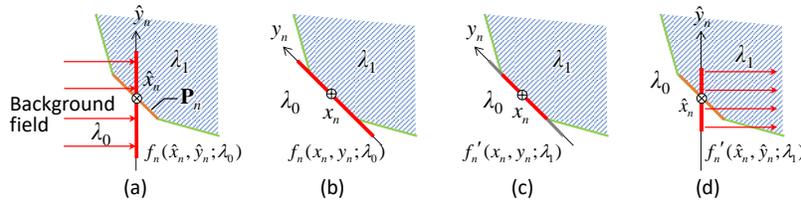


Fig. 2. Procedure for calculating the wavefield passing through polygon  $\mathbf{P}_n$ .

Superposed total field  $f_{obj}(\hat{x}, \hat{y}; \hat{z}_{obj}, \lambda_1)$  is again masked by the cross section at the object plane.

$$f'_{obj}(\hat{x}, \hat{y}; \hat{z}_{obj}, \lambda_1) = f_{obj}(\hat{x}, \hat{y}; \hat{z}_{obj}, \lambda_1) A_{obj}(\hat{x}, \hat{y}), \quad (4)$$

where  $\hat{z}_{obj}$  is the position of the object plane and  $A_{obj}(\hat{x}, \hat{y})$  is a mask function of the cross section, called the silhouette mask. Each field passing the front face polygons can be obtained by propagating the field  $f'_{obj}(\hat{x}, \hat{y}; \hat{z}_{obj}, \lambda_1)$  and using almost the same procedure as that shown in Fig. 2. Here, note that the field propagating outside the object must be calculated separately.

### 3. Optical reconstruction

We created a large-scale FP-CGH composed of 4.2 G pixels, using the proposed method. Table 1 and Figure 3 show the parameters and the optical reconstruction. The object model is a sphere with a diameter of 16 mm.

Table 1. Parameters of the created CGH.

Number of pixels ( $N_x \times N_y$ )	$65,536 \times 65,536$
Pixel pitches ( $P_x \times P_y$ )	$1 \mu\text{m} \times 1 \mu\text{m}$
Number of polygons	2400
Refraction index of object	1.5
Reconstruction wavelength	632.8 nm

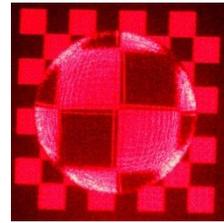


Fig. 3. Optical reconstruction of the created CGH.

### 4. Conclusion

We proposed an improved technique to render transparent objects without the restriction of the back-side shape. We calculated and created a FP-CGH. The optical reconstruction confirms correctness of the proposed method.

### 5. References

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