Occlusion processing for computer generated hologram by conversion between the wavefront and light-ray information

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Abstract. In the field of computational holography for three-dimensional (3D) display, the mutual occlusion of objects is one of the crucial issues. We propose a new mutual occlusion processing that is achieved by the conversion between the light-ray and wavefront on a virtual plane called ray-sampling (RS) plane located at near the interrupting object. The wavefront coming from background scene is converted into light-ray information at the RS plane by using Fourier transform based on the angular spectrum theory, then the converted light-rays are overwritten with those from interrupting object in the light-ray domain as an occlusion culling process. The ray information after the occlusion process is reconverted into wavefront by inverse Fourier transform at each RS point, then wave propagation from RS plane to hologram is computed by general light diffraction computation techniques. Since the light-ray information is used for the occlusion processing, our approach can realize a correct occlusion effect by a simple algorithm. In addition, high resolution 3D image can be reconstructed with wavefront-based technique. In the numerical simulation, we demonstrate that our approach for deep 3D scene with plural objects can realize a correct occlusion culling for varying observation angle and focusing distance.

1. Introduction

Holography is a superior medium for high-quality 3D displays since it reproduces the depth cues of human vision. For the electronic display of holography, the hologram pattern is calculated using the technique of computer generated hologram (CGH). Usually it is achieved by simulating physical phenomena of wavefront propagation from point/polygon sources on the object surface [1-3]. Thanks to the progress of high-speed computing, it becomes possible to define huge number of point sources in high-density on the object surface, allowing to render smooth surfaces. However, it is not easy to deal with some standard rendering technique used for photorealistic image in computer graphics, such as shading, transparency, texture mapping and light reflectance property, etc. Especially, two kinds of occlusions; self occlusion in which some surfaces are hidden by other surfaces of the same object, and mutual occlusion between different objects, are the crucial issue in CGH computation for photorealistic reconstruction.

There have been achieved self/mutual occlusion culling by masking the wavefront at the surface of the foreground [4][5]. These approaches can be considered as an approximation of physical phenomena of light interference and diffraction on plural object’s surfaces to decrease the calculation cost. However, these are still highly complicated and cannot avoid severe increase of computational cost to a large amount of light sources for higher resolution 3D scene, it is not realistic to apply for the larger hologram computation. Recently, Matsushima demonstrated the CGH computation over 4 billions of pixels for deep 3-D scene composed the plural objects [6]. In his demonstration, mutual occlusion culling is carried out by silhouette masking approach in which the wavefront from the background is interrupted by a mask of the foreground object’s orthographic silhouette. Although it
realizes a decreasing of a computation cost, the occlusion error should be observed from oblique direction since a silhouette mask is orthographically projected.

The other approach for occlusion culling is a depth-sorting technique for each light-ray in variable direction based on the general computer graphics (CG) techniques, such as holographic stereogram [7][8]. Computation cost of this approach is almost independent of the complexity of 3-D scene, depends on the number of sampled light-rays on the hologram plane. Because an occlusion culling process is much simpler, it is possible to decrease the computation cost as compared with the wavefront based approach. But because this approach is based on light-ray reproduction, deep 3D scene is blurred due to the light-ray sampling and light diffraction [9-11].

In previous work, we proposed a CGH computation approach using a ray-sampling (RS) plane that is located at near the object [12]. On the RS plane, light-ray information is sampled spatially and angularly at RS points as a set of projection images [see figure 1], and is transformed into a complex amplitude distribution by Fourier transform of projection images. The CGH pattern is thus obtained by calculating the wavefront propagation from RS plane to the hologram. In this approach, self occlusion effect of target object can be directly achieved by a general rendering technique on projection images.

In this paper, we show a new mutual occlusion culling method based on the conversion between light-rays and wavefront. Since light-ray domain is used for occlusion processing and the light propagation is calculated in wavefront domain, this approach can realize a occlusion culling with higher accuracy with simple algorithm.

![Figure 1. a scheme of CGH computation using RS plane](image)

2. Conversion between light-rays information and wavefront on a RS plane

In this section, a principle of conversion between light-rays information and wavefront on an RS plane is briefly explained. RS plane should be set near a target object to avoid an image blur due to a ray sampling and light diffraction [12]. Light-rays passing through \((i, j)\)th RS point on an RS plane compose a projection image \(p_{ij}\) viewing from a given RS point as shown in figure 2. Fourier transform of this projection image \(p_{ij}\) derives a complex amplitude distribution \(P_{ij}\) of a region centered at the same RS point based on the angular spectrum theory [13]. Applying this process for a set of projection images of all RS points and tiling obtained complex amplitude distributions on the RS plane, discrete wavefront on the whole RS plane is obtained. This process can be considered as a conversion from light-ray information into wavefront on an RS plane. By following an inverse process, i.e. executing an inverse Fourier transform of allotted wavefront for each RS point on a RS plane, wavefront on the RS plane can be converted into angular spectrum of each RS point corresponding to a light-ray information. This process can be considered as a conversion from wavefront into light-ray information.
3. **Mutual occlusion culling process by conversion between light-ray information and wavefront**

For simplicity, we assume that a target scene consists of two objects; background and interrupting object as shown in figure 3(a). If there exist more interrupting objects in a target scene, we can apply the following way for each object. Figure 3(b) shows a flow of CGH computation with proposed occlusion process. In this approach, mutual occlusion culling process should be dealt with by defining RS planes for interrupting objects. The RS plane in figure 3(a) is set near the interrupting object, and a set of projection images $p_{i,j}$ each RS point are rendered by ray-based rendering software in advance. Then the wavefront propagation from the background to the RS plane is calculated by Fresnel transform to derive the wavefront on the RS plane. The wavefront from background is then converted to the ray-information using inverse Fourier transform of allotted region for each RS point on the RS plane as mentioned in section 2.

Let $p_{b_{i,j}}$ be the light-ray information (i.e. angular spectrum) converted from wavefront of background at one RS point. Then $p_{b_{i,j}}$ is replaced by the light-rays from $p'$ if there exists the light-rays from the interrupting object. Namely, the occlusion culling at each RS point is achieved in light-ray domain. After overwriting the rays from background with the rays from interrupting object at all RS points, combined light-ray information on the RS plane is reconverted into the wavefront by Fourier transform, and whole wavefront on the RS plane considered the occlusion culling can be obtained. Finally the Fresnel transform that simulates the light propagation leads the wavefront on the hologram plane.

Since occlusion process is achieved in light-ray domain, correct occlusion culling for variable observing angle is realized easily by substituting light-rays on the RS plane. Because each RS plane and CGH plane are set in parallel, it is also possible to implement efficient calculation for light propagation by using look up table, discrete Fresnel transform algorithm by using FFT, and/or Shifted Fresnel diffraction [14].

![Figure 2. Conversion from light-ray information into wavefront on the RS plane](image)

![Figure 3. A scheme of occlusion culling process using RS plane](image)
4. Experiment

We calculated the CGH based on the proposed method and evaluated the reconstructed image by numerical simulation. The target scene consists of two objects; a checkered panel as a background and a latticework of dice as an interrupting object located at 150mm and 100mm from CGH plane respectively. We set RS planes for both objects at 5mm in front of objects. The wavefront of background was generated by using RS plane based on the method presented in ref.12, then the occlusion process was carried out on the RS plane of interrupting object. The parameters of both RS planes and CGH plane are shown in Table 1.

| RS planes       | CGH plane                  |
|-----------------|----------------------------|
| Num. of RS points | 256×256                   |
| Pitch of RS points | 64μm                      |
| Num. of rays/RS point | 32×32                  |
| Num. of pixels  | 8192×8192                 |
| Pitch of pixels | 2μm                       |
| Viewing angle   | ±3.6deg                   |

CGH calculation was executed by using a PC with a CPU of Intel Westmere-EP (2.93GHz) processor and a shared memory of 24Gbytes. The computation time for occlusion process on the RS plane including a light conversion was about 14sec for 8192×8192 pixels, and two discrete Fresnel diffraction required about 192 sec(96sec×2). In a preprocessing, we needed to render a set of projection images in about 120 min. The wavelength was 532nm in CGH calculation. By applying parallel processing or GPU computing, it is possible to decrease the calculation time, especially for occlusion processing since it includes same calculation for each RS points.

In the numerical reconstruction, initially, wavefront propagation from CGH plane to the imaging lens was calculated by discrete Fresnel diffraction. The imaging lens assumed as a human eye set at 200mm from the CGH plane. The pupil size of the lens was 7mm. Then, the wavefront inside the lens pupil was multiplied by lens phase function, finally, calculate the wavefront propagation from lens pupil to image plane.

Figure 5 shows a result of numerical reconstruction. (a)-(c) are focused on different depth as in the captions of respective figures, (d)-(f) are focused on the latticework observed from left, center and right directions in 2 degrees intervals, respectively. These results show that proposed approach can reconstruct a high resolution image for deep 3D scene without occlusion error for any observing angles and focusing distances.
5. Conclusion
We proposed an occlusion processing of CGH calculation based on the conversion between the light-ray information and wavefront. Because light-ray domain is used for occlusion processing and the light propagation is calculated in wavefront domain, this approach can realize high accuracy occlusion culling with simple algorithm. In the simulation, we showed that our method can reproduce the image with proper occlusion for the scene there exist some objects. As a future work, it should be addressed to reduce the amount of calculation of the proposed method.

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