Computer-generated holograms for 3D objects using the fresnel zone plate

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ABSTRACT

A new fast algorithm using the "host" Fresnel zone plate was proposed to improve the computational efficiency of computer-generated hologram (CGH) for 3D objects. By reading .3DS files, the spatial position information of each point of the 3D object was obtained directly. With the illumination of plane wave, the "host" Fresnel zone plate of a single point could be equal to all points located in the same depth plane – as the Fresnel zone plate was translated and superimposed along the horizontal and vertical axes. Consequently, the hologram of a 3D object could be built up by superimposing different Fresnel zone plates in the corresponding depth planes. For a digital object composed of 1060 points, it cost about 83s to generate a hologram of 1024*768 pixels. The CGH of 3D objects with the results of the reconstruction was presented in this paper, which proved the feasibility of this algorithm.

Keywords: Fresnel zone plate, computer-generated hologram, 3D information

1. INTRODUCTION

Holography is a technique in which the wavefront of a light beam can be recorded and reproduced. It can provide three-dimensional images that can fully satisfy human perception of depth-cue such as perspective, focus, binocular parallax and motion parallax. So it is seemed that holographic display is a more attractive method of displaying 3D images than others. However, recording holograms of 3D real objects demands wave interference between two intense laser beams with a high degree of coherence[1]. The optical system must be very stable, since a very slight movement can destroy the interference fringes, which contain both intensity and phase information[2]. These requirements, together with the long film exposure and development process[3], have prevented conventional hologram recorders from developing greatly. As a result, computer-generated holograms (CGH) has been widely used in many different fields, which can be generated from not only really existent objects but also the objects in a mathematical description. Reconstructing 3D images using CGH has a distance to enter application field due to the huge amount of 3D information. The structural complicacy of 3D object, which is difficult to be described by mathematic function[4], also increased the difficulty of 3D CGH.

Many algorithms of CGH for improving compute efficiency have been proposed in past years. It is common to utilize a series of 2D holograms for synthesizing 3D information to reconstruct 3D image. In "Born approximation", the 3D intensity distribution is decomposed into serial 2D planes in depth parallel to the holographic plane[5]. Due to the superposition principle the total complex amplitude in the hologram plane is the sum of all plane contributions. In

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David's method[2], many different angular 2D projections of computer-designed 3D objects are processed to yield a 2D complex matrix. Every value of this matrix corresponds to a different point of view and the matrix is arranged in the same order as the projected images are observed. Based on 2D sections or projections, these methods cost quite a bit time on the redundant information outside object which is useless for representing 3D data., thus decrease computing speed.

Any object is considered as an assemble of a mass of object points. To compute a hologram of a 3D object, we can superimpose many holograms whose image is a single point. In our scheme, the information of spatial position of each point on the surface of the 3D object is obtained directly by reading .3ds files. Then holograms corresponding to each point are computed and superimposed to generate a whole hologram of 3D object .Different from conventional holographic algorithms utilizing the formula of Fresnel diffraction, we use addition instead of exponent and multiply operation to shorten the compute time greatly.

2. FRESNEL ZONE

According to the relative position between object and holographic plane, computer-generated hologram can be classified into three types: image CGH, FFT CGH and Fresnel CGH[6]. For a 3D object, the position information includes the depth variation, thus Fresnel hologram is generally considered to used for 3D CGH. First, let us describe a hologram whose image is a single point. Such holograms are known as fresnel zone plates (Fig.1).

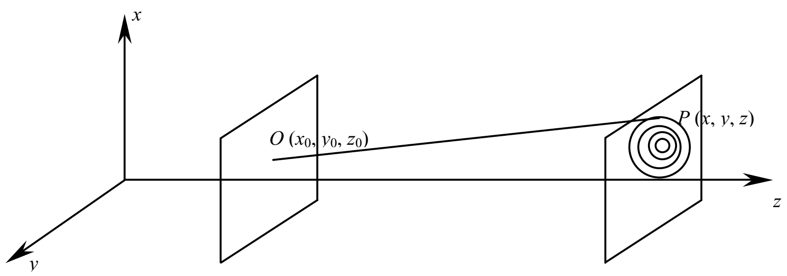


Figure 1. Beam path of Fresnel holography for a point

To generate the fresnel zone plate, the distance between each pixel of the fresnel zone plate and the point source need to be considered. From this distance, we can deduce the phase of the wavefront.

$$r = \sqrt{(x-x_0)^2 + (y-y_0)^2 + (z-z_0)^2} \tag{1}$$

$$\phi = \phi\_ref + \cos\left(2\pi r/\lambda\right) \tag{2}$$

where λ is the wavelength of the illuminating light, ϕ_ref is the phase of the wavefront when the light arrives at the plane. O(x_0, y_0, z_0) is a random object point, and P（x, y, z）is a random point on the fresnel zone plate which is generated by O(x_0, y_0, z_0). Here, we simply take the cosine of the two phase differences. The values including negative and positive are uniformly raised to generate a hologram later.

The phase of light wave varies periodically within a range from 0 to 2 pi with the distance it has traveled. If the wavefront of the point source is being interfered with the wavefront of a normal plane wave which is constant across the plane of the hologram, we need only to consider the phase of the point source's wave. In our experiment, we use 488nm plane wave normal to holographic plane, so ϕ_ref is zero. According to discussion above, the hologram whose image is a point 0.5 meter from holographic plane, ie, fresnel zone plate, is obtained. We call it "host" fresnel zone plate.

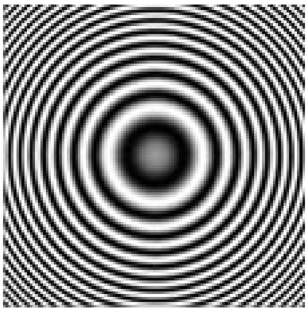


Figure 2. Fresnel zone plate pattern (256×256 pixels)

In our algorithm, the fresnel zone plate is only calculated until the Nyquist sampling limit is satisfied. So there is a limit on the size and shape of the fresnel zone plate when other factors(distance of the point source, resolution of holographic plane, angle of illumination beam, etc) is fixed. Utilizing this point, the same fresnel zone plate may be used for all pixels in a given depth plane of a 3D object, which save the computing time greatly. For simplicity, we introduce in-axis coherent plane light to generate a circular, radial symmetric fresnel zone plate. Taking advantage of symmetry, to only record the first quadrant of the zone plate is a good approach which can be looked up with little computational overhead and a cut memory. The hologram in a certain distance can be built up pixel by pixel by superimposing the "host" fresnel zone plates along the x and y axes of the hologram.

3. COMPUTATION OF 3D HOLOGRAM

To compute a hologram of 3D objects, the usual method is cutting the 3D image into a series of 2D planes along axis and superimposing the holograms of these 2D images to generate the final 3D hologram. In this paper, 3D information is needed to quantify and round. Compared with the usual method, we obtained the position data of a whole digital 3D object from .3DS files instead of 2D images and computed point by point using fresnel zone plate. It discards the redundant information and selects the data helpful for expressing the object' spatial location, which is a computationally inexpensive task. After understanding the 3ds. file's format, it is convenient to obtain the object information of spatial position and gray by reading 3ds. file.

The "host" fresnel zone plate is applicable for all points in the same depth, so many "host" fresnel zone plate is needed for a 3d object in which all points are in different depth. If computing a "host" fresnel zone plate for every point from 3ds. file, the advantage of our algorithm in computing time will not exist. Therefore all points in different depth will be round to reduce the "host" fresnel zone plates.

As known, the on-axis resolving power of human eyes is about 10'. In other words, as figure 3, when the angle formed by two beams entering human eye from A and B is less than 10', the two points (A and B) are perceived in the same depth by human eye. According to the distance (Z) from reconstructed image to eyes and interocular distance (D), we can figure out Δz, which is the foundation for rounding the 3D information along the optical axis.

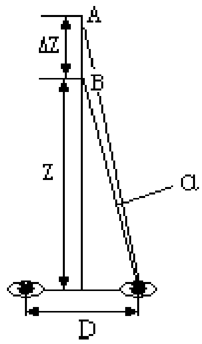


Figure 3. Schematic diagram of the on-axis resolving power of human eyes

After rounding the values of all point in z axis, the next issue is the translation and superposition of the "host" fresnel zone plate onto the plane of the hologram. It is important to keep track of borders and boundaries during the superposition process to reduce unnecessary computer. It is helpful to transform both the fresnel zone plate and the holographic emulsion to a same coordinate frame for boundaries. We will align both in UV space.

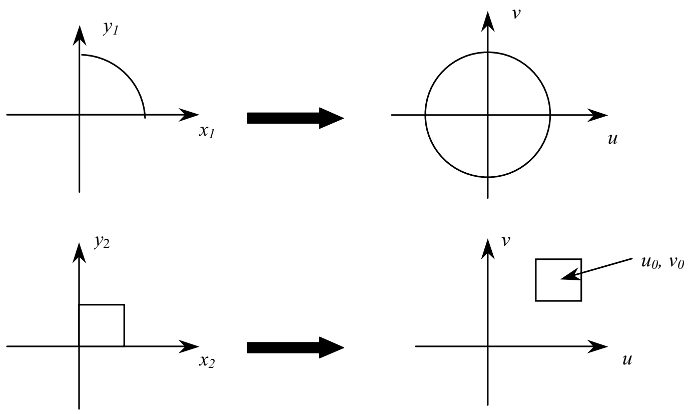


Figure 4. Transform of coordinates between the Fresnel zone plate and the holographic plane

Fresnel zone plate limits: $$u \in \left[-r, r\right] \tag{3}$$

$$v \in \left[-\sqrt{r^2 - u^2}, \sqrt{r^2 - u^2}\right] \tag{4}$$

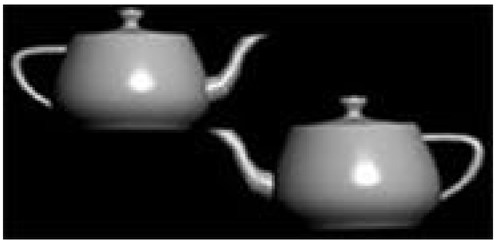
Rectangular holographic plane limits: $$u \in \left[u_0 - a/2, u_0 + a/2\right] \tag{5}$$

$$v \in \left[v_0 - b/2, v_0 - b/2\right] \tag{6}$$

Following the interval limitation above, the superimposition of fresnel zone plates of every point in the same depth is obtained fast. Superimposing the holograms in different depth, we can create the final hologram which contains all 3D information of input object.

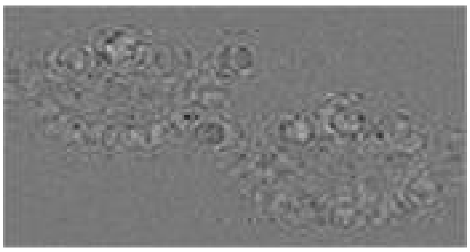
4. EXPERIMENTAL RESULT AND DISCUSSIONS

First, two teapot models in different depth were rendered by the software 3d max (Fig. 5(a)). Figure 5(b) shows the face vertex image of the two models, which contains all original sample points to compute hologram. The sampling density is variable by editing meshes in 3d max. In the experiment, we take 1060 points which is a proper balance between the amount of data and computing time. The fresnel 3D hologram is generated as figure 5(c).



(a) Render image of model

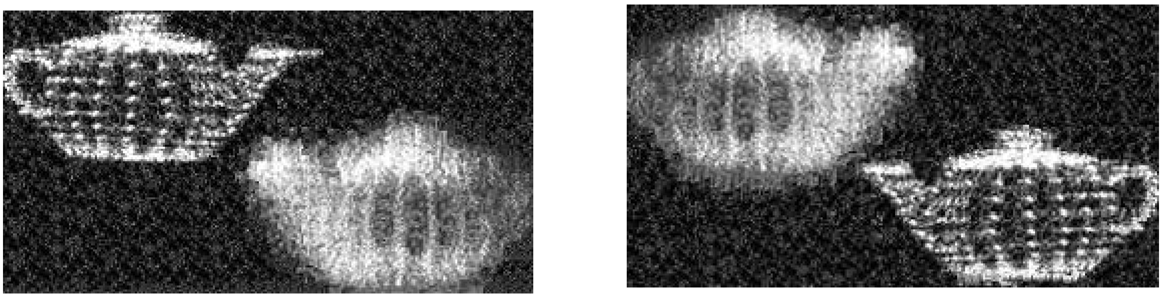
(b) Face vertex image



(c) Computed hologram

Figure 5. Experimental sample and CGH

The hologram is displayed on the transmitted LCD whose pixel numbers are 1024*768. The reference beam is a plane wave (wavelength: 488nm) that illuminates the LCD. Figure 6 shows the reconstructed results observed by the CCD for two different planes along the optical axis at distances of 655mm and 630mm from holographic plane, i.e. LCD.



(a) Reconstructed image from 655mm to LCD (b) Reconstructed image from 630mm to LCD

Figure 6. Experimental results of optical reconstruction

When CCD is away 655mm from the holographic panel, the farther pot locates just right at the focusing surface, so its reproduced image is clearer. And when away 630mm, the reproduced image of the nearer pot is clearer in like manner. Compared with two photos, it is obvious that the hologram including the depth information reconstruct the three-dimensional image which can fully satisfy human perception of depth-cue. It is a pity that the three-dimensional effect of a single object is difficult to record due to the large depth of focus field of the reconstructed system.. To represent the three-dimension of a single object, it need to reduce the depth of focus field of the reconstructed system as much as possible. Since the reconstructed image is three-dimensional, the focusing surface of CCD is located in the focusing surface of some cross-section of the reconstructed image, so, other points outside the cross-section are out-of-focus to the focusing surface of CCD in different degree, which is the main reason that the quality of the result photos is not high. The blur phenomenon weakens greatly when observed by bare eyes because of the self-adaption of human eyes. Besides, in our experiment, we displayed the hologram on a liquid crystal panel, whose pixel pitch is 17.86um. Since the resolution is lower than conventional holographic recording plate, the quality of the reconstructed image was also degraded in a certain extent. Adapting a high resolution LCD panel is being considered.

5. SUMMARY

We proposed a new fast algorithm for producing computer-generated hologram of 3D objects using the Fresnel zone plate. It takes 83 seconds to generate a 1024*768 pixels hologram of objects composing of 1060 sample points (CPU: Celeron 1.7GHz, 256M RAM, OS: Windows 2000, Compiler: Visual C++ 6.0). Obtaining the continuous three-dimensional information by reading .3DS files instead of utilizing a series of 2D sections, the hologram of all points in a certain distance can build up by superimposing the “host” fresnel zone plates. This algorithm increases the computational efficiency greatly on the premise of the complete three-dimensional information, which is propitious to making mass of 3D holograms rapidly. It need to point out, the algorithm is applicable to plane wave illumination, and when converging or diverging illumination, its advantage will be difficult to present.

REFERENCES

1. E.N.Leith, J.Upatnieks, "Wavefront reconstruction with diffused illumination and three-dimensional objects", J.Opt.Soc.Am., 54, pp.1295-1301, 1964.
2. D.Abookasis, J.Rosen, "Computer-generated holograms of three-dimensional objects synthesized from their multiple angular viewpoints", J.Opt.Soc.Am., **Vol.20**, pp.1537-1545.
3. R.J.Collier, C.B.Burckhardt, L.H.Lin, *Optical Holography*, Academic Press, New York, 1971.
4. Y.Q.Shen, H.Z.Jin, Y.Li, "Large View Angle Stereo-Holograms Obtained by the Combination of Computer and Optical Method", Opto-Elctro. Eng., **Vol.27**, pp.24-26.
5. L.C.Ferri, "Visualization of 3D information with digital holography using laser printers", Coputers&Graphics, **Vol.25**, pp.309-321.
6. Z.L. Yu, G.F.Jin, *Computer Generated Holograms*, Tsinghua University Press, Beijing, 1984.