Efficient generation of CGH using statistical redundancy of 3-D images

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Abstract

In this paper, we propose a new approach for fast generation of CGHs of a 3-D object by using the run-length encoding and N-LUT methods. In this approach, object points to be involved in calculation of the CGH pattern can be dramatically reduced and as a result a significant increase of computational speed can be obtained.

1. Introduction

Some approaches for generation of CGH patterns have been suggested.[1,2] One of them is the ray-tracing method. In this method, a 3-D object image to be generated is modeled as a collection of self-luminous points of light. And then, fringe patterns for all object points are calculated using the optical equations of diffraction and interference, and added up to obtain the whole interference pattern of the object image. However, this method has been suffered from the computational complexity, because it requires one by one calculation of the fringe pattern per image point per hologram sample [1].

To overcome this problem, a look-up table (LUT) method was presented by M. Lucente [1]. In this method, a 3-D object image to be generated is also approximated as a collection of self-luminous points of light, but all fringe patterns corresponding to point source contributions from each of the possible locations in an image volume are pre-calculated and stored in the LUT. Therefore, a great increase of computational speed in calculation of CGH pattern of object images can be obtained with this LUT method. But its drawback is the huge memory size of the LUT required for storing all fringe patterns of the object image points.

Recently, a novel look-up table (N-LUT) method to dramatically reduce the number of pre-calculated interference patterns required for generation of digital holograms was proposed [2]. In this method, a 3-D object image is approximated as a set of discretely sliced image planes with different depth, and only the fringe pattern of the center object point on each image plane is pre-calculated, so-called a principal fringe pattern (PFP) and stored in the N-LUT, so that the size of the N-LUT can be significantly reduced by comparing to that of the conventional LUT method.

Basically a 3-D image consists of depth as well as intensity data contrary to the 2-D image which has only intensity data. Just like the case of the 2-D image, adjacent pixels of a 3-D image have very similar values of intensity and depth and some of them even have the exactly same values. In other words, a 3-D image has a spatial redundancy in intensity and depth data. This spatial redundancy can be represented with the run-length encoding (RLE) method, which has been used for data reduction of the conventional 2-D images [3].

That is, by applying this conventional RLE method to the 3-D image, its spatially redundant intensity and depth data can be removed, which results in reduction of 3-D image points to be involved in generation of the CGH pattern. In another words, the calculation time required for CGH generation of the 3-D image can be dramatically shortened [3].

Accordingly, in this paper, a new approach for fast computation of CGH patterns for a 3-D object by taking into account of the spatial redundancy of the 3-D object data is proposed. That is, with the RLE method spatially redundant data of the 3-D object is extracted and re-grouped into the *N*-point redundancy maps depending on the number of the neighboring object points having the same 3-D value. Then, *N*-point PFPs corresponding to these *N*-point redundancy maps are generated from the 1-point PFPs of the conventional N-LUT method. Using these pre-calculated *N*-point PFPs, the CGH pattern for the 3-D object can be finally generated.

To confirm the feasibility of the proposed method, some experiments with a 3-D test object are carried out and the results are compared to those of the conventional methods in terms of a computational speed.

2. Proposed method

Figure 1 shows an overall block-diagram of the proposed method to fast generate CGHs for a 3-D object. The proposed method largely consists of four steps. First, spatial redundancy of the intensity and depth data of the 3-D object is analyzed by using the RLE method and they are re-grouped into the *N*-point redundancy maps according to the number of the neighboring object points having the same 3-D value. Second, *N*-point PFPs corresponding to each of the *N*-point redundancy maps are calculated by shifting and adding the 1-pont PFPs of the conventional N-LUT. Third, the CGH pattern of the 3-D object is calculated with this pre-calculated *N*-point PFPs. Fourth, the 3-D object image is reconstructed from the generated CGH pattern.

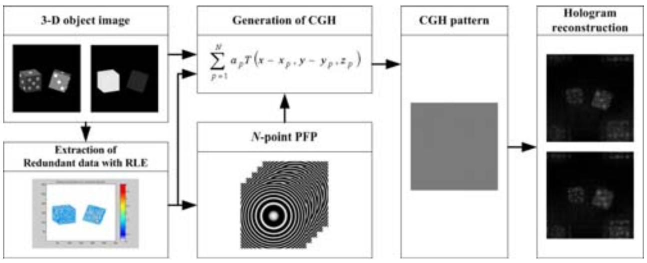
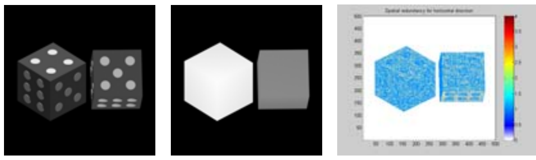


Fig. 1. Block diagram of the proposed method for generation of CGHs for 3-D images

2.1 Extraction of redundant data from a 3-D object

In general, adjacent pixels of the 3-D object image have very nearly the same brightness, color and depth values. That is, there can be a spatial redundancy both in intensity and depth data of the input 3-D image. Figure 2 shows the test 3-D object and its spatial redundancy map having a resolution of 500 × 500 pixels. Figure 2(c) shows the spatial redundancy maps extracted from horizontal scanning of the test object of Fig. 2(a) and (b) by using the RLE method. It is noted that both of horizontal and vertical scanning methods can be used for extraction of spatial redundancy maps from the test 3-D object, but here in this experiment the horizontal scanning method is employed. In these extracted redundancy maps, the blue color means that there are no adjacent object points having the same intensity and depth values, while the green, orange and red colors mean that two, three and four adjacent object-points have the same intensity and depth values, respectively. In addition, the white color means the object points of 'don't care condition'. Table 1 shows a distribution of the spatial redundancy data of the test 3-D object along the horizontal direction. As shown in Table 1, the test 3-D object consists of 78,726 object points, so that 78,726 object points have to be calculated by using the 1-point PFPs in the conventional N-LUT method.



(a) (b) (c)

Fig. 2. Input 3-D image and spatial redundancy data (a) Intensity image (b) Depth image (c) spatial redundancy map

Table 1. Calculated object points for re-grouping

Calculation points	Number of spatial redundancy data of the test 3-D object	
	Conventional method (1-point)	Proposed method (2-point)
1-point	78,726	51,828
2-point	-	13,449
Total	78,726	65,277
Reduction ratio	-	17.1%

However, in case a 2-point redundancy map is used 51,828 and 13,449 object points can be calculated with the 1-point and 2-point PFPs, respectively. Thus, only 65,277 object points are involved in calculation of the CGH pattern in the proposed method, which results in reduction of 13,449 object points in number compared to the conventional N-LUT method. In other words, for the test 3-D object of Fig. 2(a) and (b) the number of the object points involved in calculation of the CGH pattern can be reduced by 17.1% (2-point case) compared to the conventional N-LUT method.

2.2 *N*-point PFPs for adjacent object points

Figure 3 shows a flowchart to generate the *N*-point PFPs for an arbitrary depth plane using the proposed method. Here we consider three adjacent points located on a depth plane of z_1: $A(0, 0, z_1)$, $B(d, 0, z_1)$ and $C(2d, 0, z_1)$ as shown in Fig. 3(a). And Fig. 3(b) shows the *1*-point PFP for an arbitrary depth plane of z_1 in the conventional N-LUT. Then, the 3-point PFP for three adjacent object points can be calculated by simple shifting and adding operations of the 1-point PFP.

That is, the diffraction pattern of the object point $A(0, 0, z_1)$, which is located on the center of the image plane of z_1, can be obtained by simply locating the center of the 1-point PFP of Fig. 3(b) on this object point as shown in Fig. 3(c-1). Then, the diffraction pattern for the object point $B(d, 0, z_1)$ can be obtained by shifting the center of the 1-point PFP of Fig. 3(b) to the x-direction with an amount of $+d$ as shown in Fig. 3(c-2). Likewise, the diffraction pattern for the object point of $C(2d, 0, z_1)$ can be obtained by shifting the center of the 1-point PFP of Fig. 3(b) to the x-direction with an amount of $+2d$ as shown in Fig. 3(c-3). By adding these three shifted versions of the 1-point PFP, the 3-point PFP can be finally obtained, which is shown in Fig. 3(d). Figure 4 shows three examples of N-point PFPs, in which Fig. 4(a), (b) and (c) shows the 1-point, 2-point and 3-point PFP, respectively.

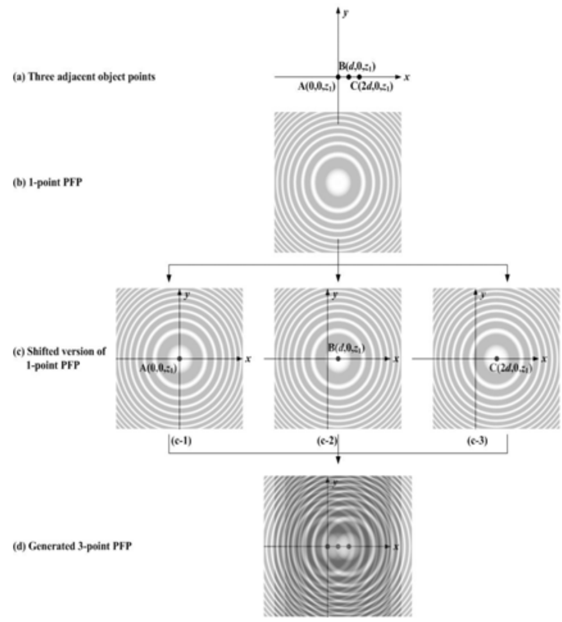
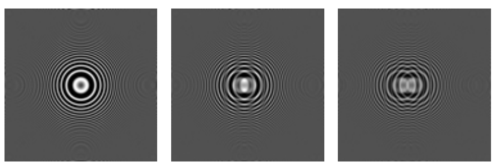


Fig. 3. Generation process of the 3-point PFP



(a) (b) (c)

Fig. 4. Examples of N-point PFPs (a) 1-point PFP (b) 2-point PFP (c) 3-point PFP

2.3 Calculation of CGH patterns

Figure 5 shows a flowchart to generate a CGH pattern for an arbitrary 3-D object using the proposed method. Here a 3-D object is modeled as the depth-dependently sliced image planes and spatially redundant data of the object is extracted by using the RLE method. Then, image planes are sequentially selected and the fringe patterns for object points existed on this image plane are calculated by using the N-point PFPs. By adding the fringe patterns calculated for all image planes of the 3-D object, a final CGH pattern is generated.

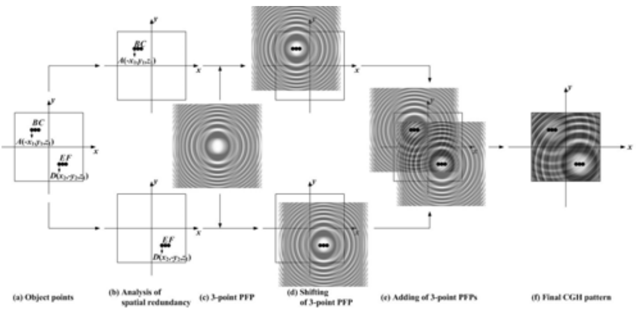


Fig. 5. Generation process of a CGH pattern with the proposed method

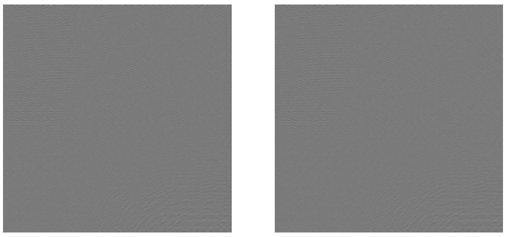
Here we consider a test image plane of an arbitrary 3-D object, which locates on the depth plane of z_1 and has six object points: $A(-x_1, y_1, z_1)$, $B(-x_1+d, y_1, z_1)$, $C(-x_1+2d, y_1, z_1)$, $D(x_2, -y_2, z_1)$, $E(x_2+d, -y_2, z_1)$, $F(x_2+2d, -y_2, z_1)$ as shown in Fig. 5(a).

As you can see in Fig. 5(b), there are two groups of adjacent three object points: $A(-x_1, y_1, z_1)$, $B(-x_1+d, y_1, z_1)$, $C(-x_1+2d, y_1, z_1)$ and $D(x_2, -y_2, z_1)$, $E(x_2+d, -y_2, z_1)$, $F(x_2+2d, -y_2, z_1)$. They all have same intensity and depth values and they are separated each other with a discretization step of d. Therefore, the CGH patterns for these three adjacent object points can be calculated just by using the 3-point PFP of Fig. 4(c). That is, the fringe pattern for three adjacent object points of $A(-x_1, y_1, z_1)$, $B(-x_1+d, y_1, z_1)$, $C(-x_1+2d, y_1, z_1)$ can be obtained by simply shifting the 3-point PFP of Fig. 4(c) to the x and y-direction with amounts of $-x_1$ and y_1, respectively as shown in Fig. 5(d). Similarly the fringe pattern for another three adjacent object points of $D(x_2, -y_2, z_1)$, $E(x_2+d, -y_2, z_1)$, $F(x_2+2d, -y_2, z_1)$ can be also obtained just shifting the 3-point PFP of Fig. 4(c) to the x and y-direction with amounts of x_2 and $-y_2$, respectively, which is shown in Fig. 5(d).

Accordingly, by adding these shifted versions of the 3-point PFP for two groups of three adjacent object points the CGH pattern for this image plane of the 3-D object can be obtained, which is shown in Fig. 5(e).

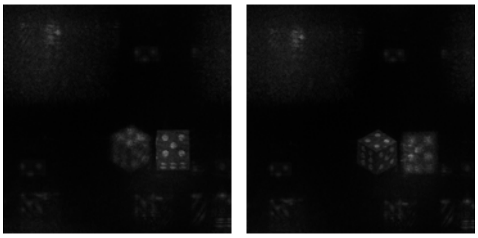
Here a size of the CGH pattern obtained by overlapping two kinds of shifted versions of the *3*-point PFP will be increased comparing to that of the original fringe pattern, so that it should be tailored as a pre-determined size as shown in Fig. 5(f).

Figure 6 shows calculated hologram patterns using the conventional and proposed methods. Two object images computationally reconstructed from the CGH patterns of Fig. 6 are shown in Fig. 7.

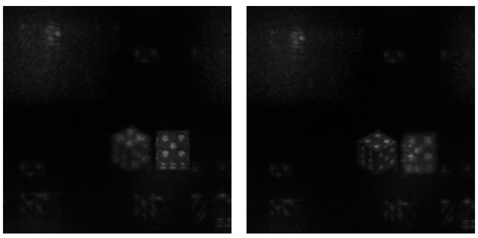


(a) N-LUT method (b) 2-point map

Fig. 6. Generated hologram patterns using the conventional and proposed methods



(a) N-LUT method



(b) 2-point map

Fig. 7. Object images reconstructed from the CGH patterns generated with the conventional N-LUT and proposed methods at the distance of 650 and 850 *mm*

Table 2 shows the comparison results on computation time needed for generation of the CGH pattern of the test 3-D object in the conventional and proposed methods. Here in the experiment, a PC system employing an Intel Pentium Core^{TM}2 Quad operating at 2.4 GHz, a main memory of 2 GB and an operating system of Microsoft Windows XP as well as the Matlab 7.4 are used.

Table 2. Calculation time and total memory space

	N-LUT method	Proposed method
Computation time for one object-point (*ms*)	11.76 (100%)	9.53 (81.0%)

In Table 2, computation time for one object-point means the amount of average computation time required for one object point source. As you can see in Table 2, in the proposed method the computation time can be decreased by a factor of 81.0% for 2-point spatial redundancy by comparing to those of the conventional N-LUT method. Finally, from these experimental results suggest a feasibility of the proposed method to fast generation of CGH patterns with a dramatically reduced LUT.

3. Summary

In this paper, a new approach for fast generation of CGH patterns of the 3-D object using the RLE and LUT methods has been proposed. In the proposed method, the object points to be involved in calculation of the CGH pattern were dramatically reduced by removing the spatially redundant data from the given 3-D object and as a result a significant improvement of computation speed was obtained. Experimental results with test objects showed that computation time was resuced by 81.0% by comparing to that of the conventional N-LUT method when the 2-point PFPs were employed.

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4. References

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