Calculation Reduction Method for Computer-Generated Hologram using Angular Redundancy and Color Space Conversion

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Keywords: electro-holography, computer-generated hologram, calculation reduction, color space

ABSTRACT

We propose a calculation reduction method for computational holograms using angular redundancy of light field by color space conversion. The angular redundancy could be enhanced by the properties of color space. We confirmed that the computational complexity can be reduced by about 20%.

1 INTRODUCTION

Holography is a technology that makes it possible to record and reproduce three-dimensional (3D) information by utilizing interference and diffraction of light waves. Electro-holography is also a technique to calculate a computer-generated hologram (CGH) from light field data by simulating propagation and interference of light waves on a computer. It is also possible to reproduce a moving 3D image from CGHs.

The computational complexity of CGH calculation is enormous. Therefore, various methods have been proposed to reduce the computational complexity. One of them is a method by avoiding the recalculation of angular redundancy of light field [1]. In this method, the hologram is divided into multiple sub-holograms. These sub-holograms are generated from images of 3D objects rendered from different viewpoints. These images are called element images. Then, when calculating adjacent sub-holograms, the computational complexity can be reduced by sharing the calculation results for the common component. Fig.1 shows an overview of this method. Therefore, the percentage of the common components affects the calculation speed. In order to increase this percentage, we focused on the CGH calculation method using YCbCr color space [2]. Human eyes are sensitive to changes in brightness(Y), but insensitive to changes in color differences (Cb, Cr). Therefore, even if Cb and Cr components are thinned out, they have little effect on the image quality. Using this property, we expected that it would be possible to increase the percentage of common components for Cb and Cr components.

In this paper, we propose a computational complexity reduction method for CGH computation using angular redundancy and color space conversion.

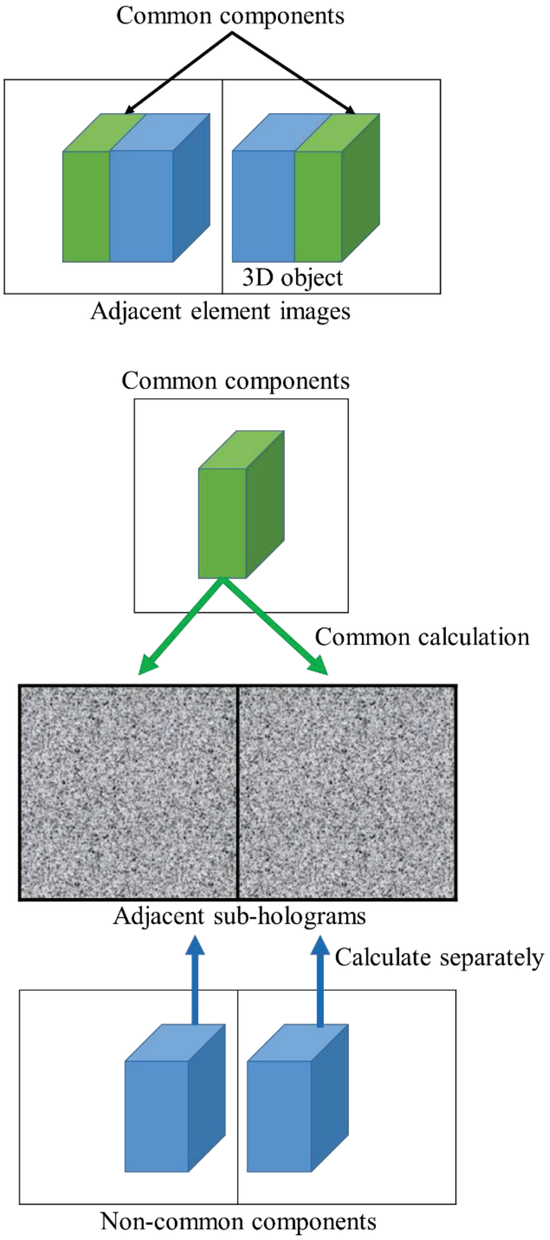

Fig. 1 Overview of the method by avoiding the recalculation of angular redundancy of light field.

2 PROPOSED METHOD

To confirm the effect of the proposed method, we measured the percentage of the common components for each of RGB color space and YCbCr color space. As 3D objects, we used bunny and dinosaur. The distance between the camera and the bunny is 30 cm, and the dinosaur is about 1 cm behind it. The object is rendered from 16 × 16 viewpoints. The number of pixels in the element image is 120 × 120. Therefore, the total number of pixels is 1920 × 1920. These processes were performed by OpenGL. Fig.2 shows an example of a multi-viewpoint image. To make it easier to see, we only show 4 × 4 viewpoints in Fig. 2. Each bit depth of the color component is 8 bits, and the number of depth layers is 16.

Eq. (1) shows the formula used to convert from RGB color space to YCbCr color space [3].

$$\begin{aligned} Y &= 0.257R + 0.504G + 0.098B + 16 \\ Cb &= -0.148R - 0.291G + 0.439B + 128 \\ Cr &= 0.439R - 0.368G - 0.071B + 128 \end{aligned} \quad (1)$$

We describe how to calculate the percentage of common components. Adjacent elemental images are compared pixel by pixel. Then, the pixels in which the color component and the depth component coincide are treated as a common component. The ratio of the number of common components to the total number of pixels in the elemental image is defined as the percentage of common components.

For the method of thinning out CbCr component, a simple thinning method does not work. The simple thinning method replaces the value of four adjacent pixels with the value of one pixel. In this case, as shown in Fig.3, common components may be lost. To solve this problem, we devised another thinning method. Fig.4 shows the overview. In this method, when comparing adjacent element images, four pixels are compared together. If only 1-pixel matches, four pixels are treated as common. Therefore, as shown in Fig.4, YCbCr components are partially thinned to 4:1:1. This method has two advantages. The first is to prevent the disappearance of common components. As a result, the percentage of common components can be increased without waste. The second is that quality degradation due to thinning can be minimized. Because the simple method thins out the whole image, but our method thins out only partly.

For the YCbCr color space, the percentage of common components was measured in three cases. The first does not thin out the CbCr component. The second is a simple thinning method. The third is the proposed thinning method shows in Fig.4.

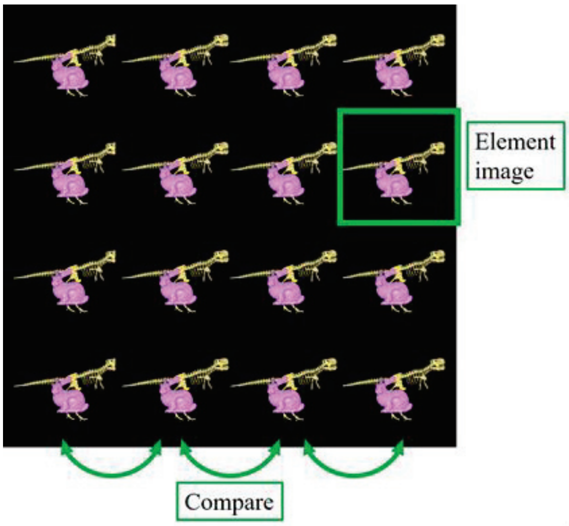

Fig. 2 Rendered image from multiple viewpoints.

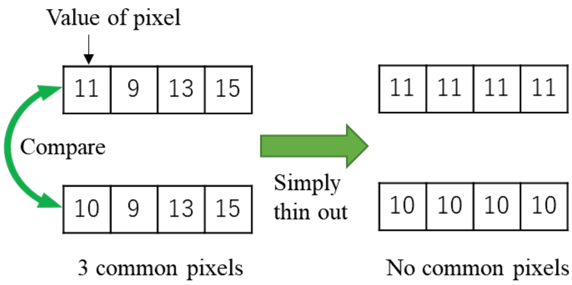

Fig. 3 Lost common components by simply thinning out.

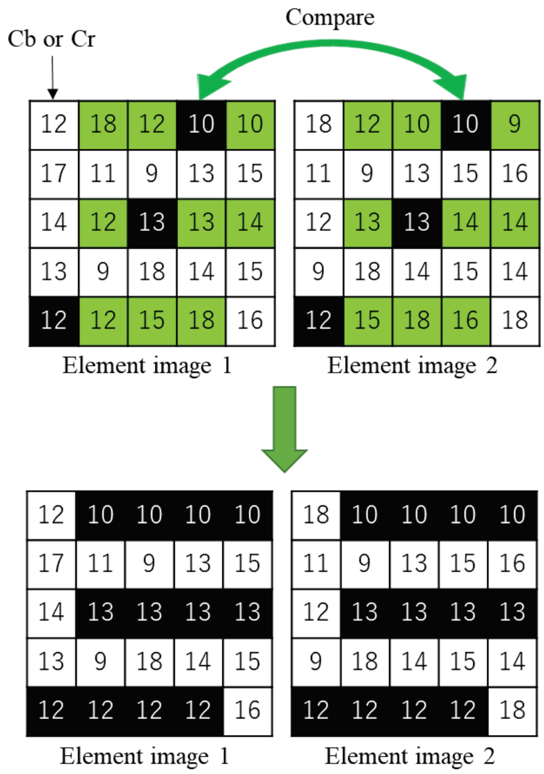

Fig. 4 How to compare Cb and Cr components.

3 RESULTS

Tables 1 and 2 show the percentage of common components for RGB and YCbCr color spaces. From Table 2, it is not enough to increase the percentage of common components only by color space conversion or by simple thinning. On the other hand, our proposed method succeeded in increasing the percentage of common components by about 20% compared to other methods. Therefore, the effectiveness of the proposed method was confirmed.

Table 1 Percentage of common components for RGB

R	G	B	Average
6.8%	3.6%	9.1%	6.5%

Table 2 Percentage of common components for YCbCr

	Y	Cb	Cr	Average
(1)	3.0%	6.1%	6.7%	5.3%
(2)	3.0%	7.9%	8.3%	6.4%
(3)	3.0%	40.5%	41.4%	28.3%

(1) Not to thin out the CbCr component.
(2) Simple thinning method.
(3) Proposed thinning method.

4 DISCUSSION

From the above results, it is expected that using the YCbCr color space and the proposed thinning method will reduce the amount of hologram calculation by about 20% compared to the hologram calculation in the RGB color space.

In practice, to use the YCbCr color space, calculations for color space conversion are required. Let N be the total number of pixels in an element image. Also, let M be the total number of pixels in a CGH. Then, the computational complexity of color space conversion is $O(N)$. On the other hand, the computational complexity of CGH is $O(NM)$. Therefore, the computational complexity of CGH is dominant in the calculation. For the above reasons, the total computational complexity can be reduced even if the computational complexity of color space conversion is considered.

In the proposed method, the YCbCr components are partially thinned out. So, the quality of element images may be degraded. Therefore, we compared the image quality of the original image and the image that the YCbCr components are thinned out. Fig. 5 shows the images used for this comparison. We used SSIM [4] to evaluate the image quality. As a result, the SSIM between Fig.5(a) and Fig.5(b) is 0.992. It shows that thinning out the Cb and Cr components hardly reduce the quality.

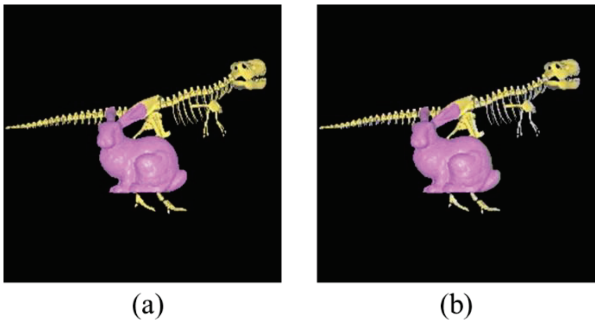

Fig. 5 (a) RGB element image, (b) thinned YCbCr element image.

5 CONCLUSIONS

Generally, to calculate full-color CGHs, the computational complexity is tripled compared to the case of a monochrome CGH. However, full colorization is essential to put electro-holography into practical use. Therefore, the method to reduce the computational complexity becomes more important.

We focus on the method which reduces the CGH complexity using the angular redundancy of adjacent sub-holograms. In addition, we devised a method to improve this method by using the property of YCbCr color space.

Then, we confirmed that the proposed method was expected to reduce the computational complexity by about 20% compared to the conventional method.

ACKNOWLEDGMENT

This work was partially supported by Japan Society for the Promotion of Science (JSPS) (19H04132,19H01097).

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