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Depth Perception for Reproduced Images in Integral Photography

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ABSTRACT

Integral photography was generated from multi-view stereoscopic images. The prototype equipment was used to evaluate the linearity of the reproduced depth distance and the accommodation response. As a result, we found that the reproduced depth distance is linear and there is no conflict between convergence and accommodation.

1 INTRODUCTION

It is said that the reproduction of the object which is similar to the real object is possible by the integral photography using the light field reproduction. It is also pointed out that there is no conflict between convergence and accommodation, and that visual fatigue does not occur. In this article, we describe the generation method of the integral photography based on the computer. In addition, we describe the experimental examination on the linearity of the depth distance in the reproduction image and the response of convergence and accommodation.

2 GENERATION OF INTEGRAL PHOTOGRAPHY

In the generation of the integral photography based on the computer, the following methods are considered: a method for pick-upping an object by providing a camera array corresponding to element images, and a method for generating an element image by pixel position conversion from a multi-view stereoscopic image by pick-upping a multi-view stereoscopic image for the object[(1)]. In addition, integral photography is obtained by attaching a convex lens array to the obtained element image.

Fig. 1 shows a process of generating an elemental image from a multi-view stereoscopic image to a display LCD (LCD; liquid crystal display) by pixel position conversion. As shown in the figure, the optical axis of each camera of the camera array is directed to a fixation point, and picking-up is performed.

Fig. 2 shows a method of generating an elemental image by pixel position conversion from a multi-view stereoscopic image. The number of multi-view stereoscopic images to be picked-up (M_{max}, N_{max}) becomes

$$(M_{max}, N_{max}) = (d/r, d/r)$$

where d is the diameter of the lens and r is the pixel pitch of the LCD for display. Next, the number of pixels (j_{max}, i_{max}) in one image (M, N) of the multi-view stereoscopic image becomes.

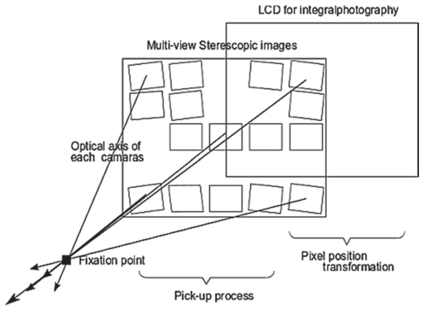

Figure 1 Generation of integral photography

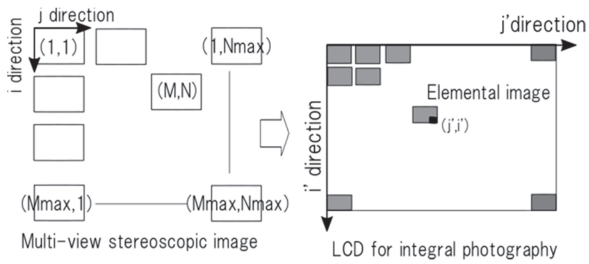

Figure 2 Method of pixel position conversion

$$(j_{max}, i_{max}) = (j'_{max}/N_{max}, i'_{max}/M_{max})$$

(j'_{max}, i'_{max}) is the number of pixels and lines of the LCD for display.

An elemental image is obtained from the picked-up multi-view stereoscopic image by using pixel position conversion. The pixel position and line position (j', i') of the LCD for display are as follows.

$$(j', i') = \left(d/r \times j - (N-1), d/r \times i - (M-1)\right)$$

M and N denote the (M, N) th image and (j, i) the pixel position and line position of the (M, N) th image of the multi-view stereoscopic image. Integral photography is obtained by attaching a lens array to an elemental image of an LCD obtained by pixel position conversion.

3 SPECIFICATIONS OF PROTOTYPE INTEGRAL PHOTOGRAPHY

The main specifications of the prototype integral

Integral photography equipment		
Panel	4.8inch LCD(HDTV format) [Ortus Technology Co. Ltd.]	
	Dot pitch 55.50 μm	
Lens array	1mmx1mm square alignment	
	Focal length 3.3mm	
Integral photography display		
Spatial Resolution	106 dot x 60 line	
Elemental image	18 x 18 dot	

Figure 3 Specification of prototype integral photography

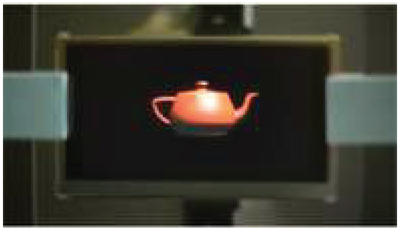

Figure 4 Photograph of prototype integral photography

photography are shown in Fig. 3. As shown in the figure, the size of the LCD for display is 4.8 inches in HDTV format. The pixel pitch is 55.5 μm. The lens array is a convex lens array of 1 mm in diameter. The elemental image is 18 x 18 dots, and the maximum spatial resolution is 106 x 60 dots. A photograph of the prototype integral photography is shown in Fig. 4. C++, OpenGL, and OpenCV were used for the generation of the integral photography.

4 DEPTH REPRODUCIBILITY OF INTEGRAL PHOTOGRAPHY

4.1 Calculation of Reproduced Depth Distance

First, the depth distance that is reproduced when the object is placed in front of the fixation point is obtained. Fig. 5 shows a case where an object is placed in front of the fixation point and an image is picked-up by the cameras on both the left and right ends of the camera array. The following relationship is obtained from the figure(2)(3).

$$\theta_C : p = {}^{\theta_c}/_2 - \theta_{3L} : S_L$$
$$\theta_c : p = {}^{\theta_c}/_2 + \theta_{3R} : S_R$$

where θ_c and p are the image angle of view and the number of pixels of one camera of the camera array. θ_{3L} and θ_{3R} are the difference between the angle formed between the principal point of the lens and the fixation point, and the angle formed between the principal point of the lens and the object, in the cameras on the left and right ends. S_L and S_R are pixel positions where the object is projected by the cameras at the left and right ends.

Therefore, the pixel positions where the object is projected by the camera at the left and right ends are S_L and S_R.

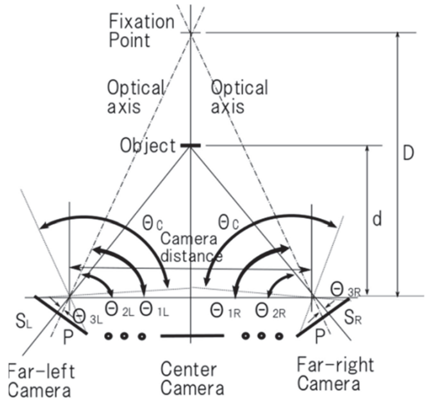

Figure 5 Condition of picking-up of an object located in the front of fixation point

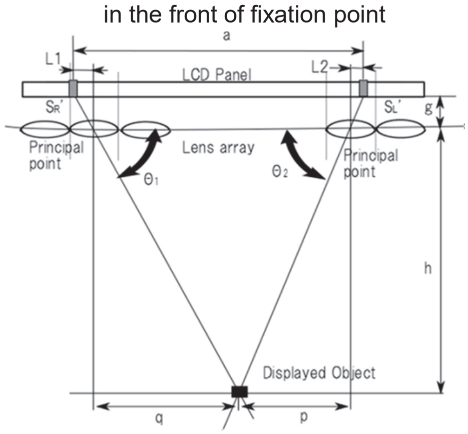

Figure 6 Condition of reproduction of an object located in the front of fixation point

$$S_L = \frac{p}{\theta_c} \times \frac{\theta_c - 2\theta_{3L}}{2}$$

$$S_R = \frac{p}{\theta_c} \times \frac{\theta_c - 2\theta_{3R}}{2}$$

S_L and S_R become the pixel of the elemental image of LCD for the display by the pixel position conversion.

Fig.6 shows the converted pixel positions $S_L{'}$ and $S_R{'}$ of the display LCD. In this figure,

$$a = L_1 + q + p + L_2$$
$$h + g = (q + L_1)\tan\theta_1$$
$$h + g = (p + L_2)\tan\theta_2$$

Here, a indicates the interval between $S_L{'}$ and $S_R{'}$. L^1 and L_2 are intervals to the centers of the elemental images corresponding to the lens principal points in the element images to which $S_L{'}$ and $S_R{'}$ belong. p and q are the intervals between the principal point of the lens corresponding to the element image to which $S_L{'}$ and $S_R{'}$ belong and the horizontal position of the reproduced object.

On the other hand, the depth distance reproduced from the lens array surface is assumed to be *h*, and the distance between the lens array and the display LCD is assumed to be *f*. Assuming that the angle formed by the principal point of the lens corresponding to the element image to which $S_L{}'$ and $S_R{}'$ belong and the reproduced subject is θ_1 and θ_2, the following equation is established. Therefore,

$$a = L_1 + \frac{h+g}{tan\,\theta_1} - L_1 + \frac{h+g}{tan\,\theta_2} - L_2 + L_2$$

As a result, the reproduced depth distance *h* is expressed by the following equation.

$$h = a \times \frac{tan\,\theta_1\, tan\,\theta_2}{tan\,\theta_1 + tan\,\theta_2} - g$$

When the object is located far from the fixation point, the determination can be made in the same manner. When the object is located further than the fixation point, the reproduced depth distance is expressed by the following equation. For convenience, minus indicates the far direction than the display screen.

$$h = -a \times \frac{tan\,\theta_1\, tan\,\theta_2}{tan\,\theta_1 + tan\,\theta_2} - g$$

Using the obtained results, we calculated the depth distance reproduced by the prototype integral photography. In the calculation, the camera array and the object were placed in the space of OpenCV. The distance from the camera array to the fixation point was 400,700, 1000, 1300, and 1600, and the position of the object was expressed as the ratio of the distance to the fixation point, and the ratio was varied from 0.4 to about 1.9. The interval between the camera arrays is 200. Fig. 7 shows the calculation results. In the figure, the horizontal axis shows the ratio of (position of the subject)/(Position of the fixation point). The vertical axis is the depth position to be reproduced, and the unit is mm. From this figure, it can be seen that if the fixation point is set relatively far and the object is placed near the fixation point, the depth distance to be reproduced changes linearly according to the position of the object.

4.2 Subjective Evaluation of Reproduced Depth Distance

Fig. 8 shows the experimental conditions of the subjective evaluation experiment on the perception of the depth distance reproduced by the prototype integral photography. The visual target used in the experiment was Maltese cross generated with the fixation point of 1400. The viewing distance was 60 cm, and the target was displayed every 2 cm between 46 cm and 74 cm. Subjects are 3 persons, and the observation time is 5 seconds. The evaluation was based on the scale method. Fig.9 shows a photograph of experiment apparatus.

Fig. 10 shows the experimental results. In the figure, the horizontal axis indicates the reproduced depth position, and the vertical axis indicates the evaluated

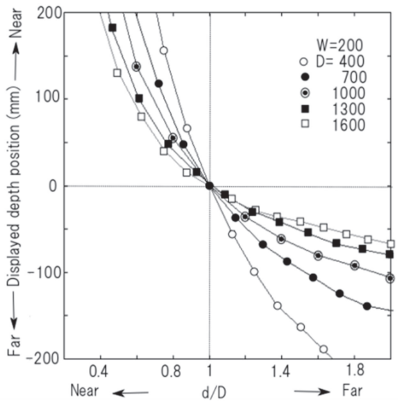

Figure 7 Calculation result of depth distance

Visual target	Maltese cross
Viewing distance	60cm(Display position)
Visual target position	46cm−74cm (2cm step)
Viewing time	5 sec
Test method	Scale evaluation
Number of subject	3 persons

Figure 8 Experimental condition of perception of depth distance

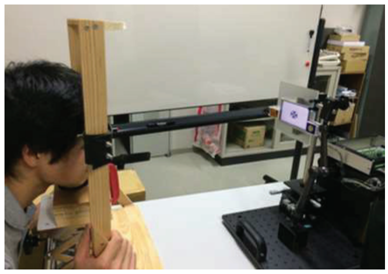

Figure 9 Photograph of experiment apparatus

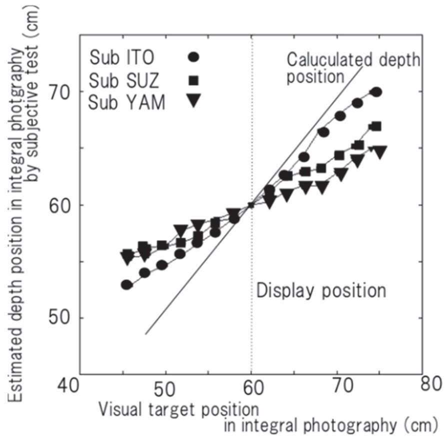

Figure 10 Experiment result

depth distance. The solid line in the figure is a calculated value. This result shows that the perception of depth distance is almost linear. Therefore, in integral photography generated from multi-view stereoscopic images, the reproduced depth distance can be regarded as a linear if appropriate parameters are selected. However, the perception of the reproduced depth distance is almost 1/2 of the calculated value, although there is individual difference.

5 ACCOMMODATION RESPONSE OF INTEGRAL PHOTOGRAPHY

The accommodation response in the prototype integral photography was measured and evaluated[(4)]. Fig. 10 shows the experimental conditions. Maltese cross was used as a visual target. Viewing distance is 60 cm. The range of the depth to which the visual target was displayed was 46 cm in front and 72 cm in back, and it changed every 2 cm. WAM -5500 (Shigiya Machinery Works Ltd.) was used to measure accommodation responses. Subjects are 3 persons, and the measurement time is 5 seconds. Three measurements were made on one subject and the mean value was used as the measurement data. Fig.11 shows the measurement results. In the figure, the horizontal axis indicates the display position of the target (meter angle -1), and the vertical axis indicates the measured value of the accommodation response (Diopter, abbreviated as D). The solid line in the figure shows Donder's line, and this line shows the case where the theoretical convergence position coincides with the accommodation response position. The vertical broken line in the figure is in the range of the depth of field ± 0.2 D. The position of the display device is 1.67 D, which is indicated by a chain line in the figure. The results show three subjects.

In the measured range, the results of the accommodation response vary continuously and linearly in and out of depth of field for all subjects. Since the position of the target changes almost linearly, it is presumed that the accommodation response also changes linearly in response to it. Therefore, there is no conflict of convergence and accommodation observed in stereoscopic image by binocular fusion, and it can be guessed that there is no visual fatigue by this factor.

6 CONCLUSION

On the basis of the computer, the generation method of the integral photography by the pixel position conversion from the multi-view stereoscopic image was developed, and the prototype integral photography was produced. The linearity of the depth distance reproduced using the prototype integral graph photography was examined. As the result, it was found that the reproduction of the linear depth distance was obtained, when the appropriate imaging parameter was set. And, it was found that there was no conflict of convergence and accommodation by measuring the accommodation response for the prototype integral photography. Therefore, in the integral photography, it is guessed that the visual fatigue by this factor does not occur.

Visual target	Maltese cross
Viewing distance	60cm
Display depth distance	Near 14cm(46cm) to Far 12cm (72cm) every 2cm
Measurement equipment	WAM-5500 [Sigiya Machinery Works Ltd.] 7Hz Sampling Frequency
Number of subject	3 persons
Measurement time	3times(5sec period)

Figure 11 Experimental condition for measurement of accommodation response

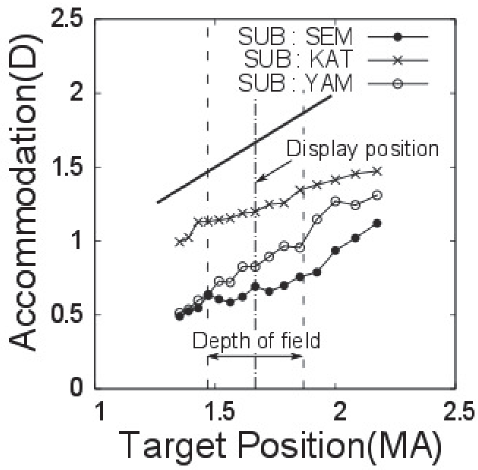

Figure 12 Experimental result of accommodation response

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