Design and Analysis of Integral Imaging Based 3D Light-Field Display

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ABSTRACT

Using the Computer Generated Elemental Image (CGEI) algorithm, we realize the generation of elemental image from the 2D image and its depth map, and use the ray-tracing method to simulate and analyze the reconstructed planes of different depths. Finally, naked eye 3D display and VAC free can be achieved.

1 Introduction

The integral imaging based 3D light field display can restore its Light-Field information [1][2][3][4], reconstruct different images in different depth planes, and realize the floating projection effect. In the metaverse, AR\VR wearable devices, smart cars HUD, medical care, entertainment, art performances and other scenarios, naked-eye 3D display is one of the most crucial requirements for the coming future.

2 Experiment

2.1 Computer Generated Elemental Image (CGEI) algorithm

Fig. 1 shows the design principle of the CGEI algorithm. Using the reversibility of light, the floating image can be restored during the display process.

The calculation principle is that we assign all the pixels of the 2D image to relative three-dimensional coordinates in space [5], and after ray tracing each image pixel to the center of the lens array, after excluding the light beyond the image area of the corresponding lens, the elemental image can be obtained. In order to calculate the elemental image more accurately, we wrote a set of Computer Generated Elemental Image algorithm, the detailed process is in Fig. 2.

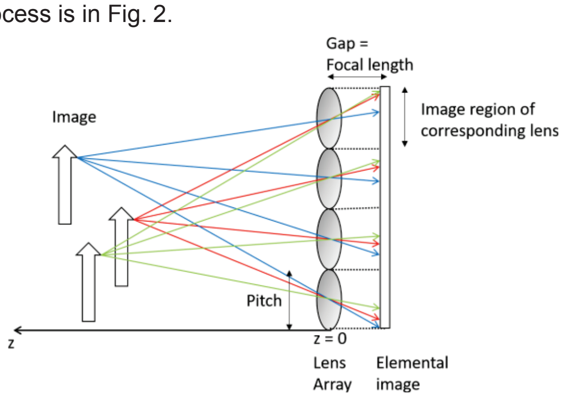


Fig. 1 Design principle of CGEI algorithm

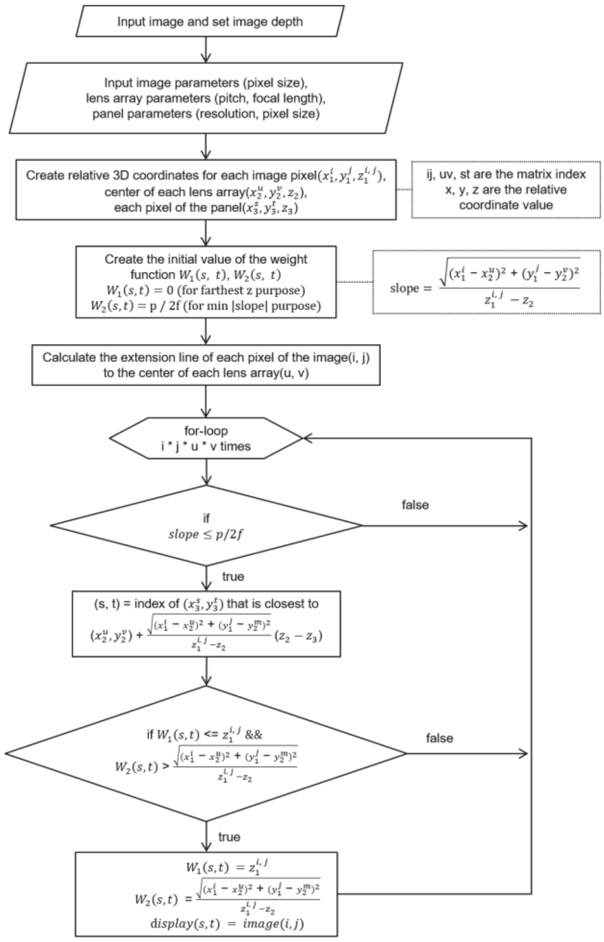


Fig. 2 CGEI algorithm flow chart.

In the CGEI algorithm, we set the weight functions w1 and w2 because the size and pixel size of the image and elemental image can be different. When a pixel of an elemental image corresponds to multiple image pixels, a weight function needs to be used to judge.

2.2 Calculated Elemental Image

Using ray reversibility, we use the parameters to be displayed as the parameters to be collected in the algorithm, as shown in Table 1. We input an image of ABC as shown in Fig. 3, and set the depth of "A" to 200mm, the depth of "B" to 105.37mm, and the depth of "C" to 48mm. Using the CGEI algorithm flow chart in Fig. 2, the elemental image is calculated as follows in Fig. 4.

Table. 1 Light-Field Display parameters

Image parameters	
Resolution (#)	2022 * 1404
Pixel size (mm)	0.1
Lens array parameters	
Focal length (mm)	8
Pitch (mm)	2
Number(#)	104 * 78
Panel parameters	
Resolution (#)	2048 * 1536
Pixel size (mm)	0.1
Screen size (inch)	10.1

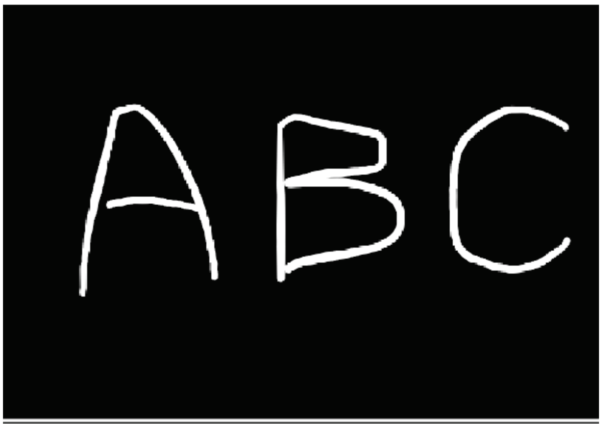


Fig. 3 Original 2D image

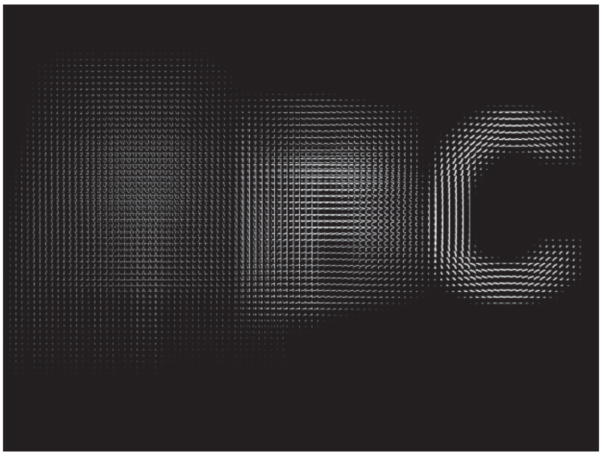
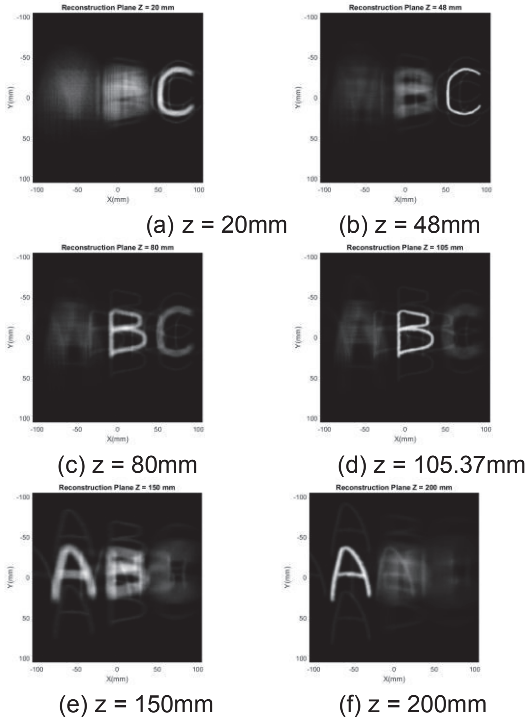


Fig. 4 Calculated elemental image

3 Results

3.1 Ray-tracing method

Considering the real display environment, we use the Monte Carlo ray tracing method of the software LightTools for simulation and analysis. We set the Light-Field Display to the specifications of Table. 1, and set the panel light output angle to 0~90 degrees, Lambertian distribution. And set the receiver depth to 20mm, 48mm("C"), 80mm, 105.37mm("B"), 150mm, 200mm("A"), and the results are shown in Fig 5.



(a) z = 20mm (b) z = 48mm (c) z = 80mm (d) z = 105.37mm (e) z = 150mm (f) z = 200mm

Fig. 5 Reconstruction plane at different depth.

3.2 Noise analysis

When the light field is displayed, the light will pass through the lens that does not belong to it, which will cause noise after integral imaging. To quantify the noise level, we use the noise-free result as a reference to calculate the mean-square error (MSE) and peak signal to noise ratio (PSNR). Given a noise-free m × n monochrome image I and its noisy image K, MSE is defined as Eq. (1), PSNR is defined as Eq. (2).

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2 \quad (1)$$

$$PSNR = 10 \cdot log_{10}\left(\frac{MAX_I^2}{MSE}\right) \quad (2)$$

After calculation, the PSNR of "A" word at z = 200mm is 31.83dB, the PSNR of "B" word at z = 105.37mm is 27.67dB, and the PSNR of "C" word at z = 48mm is 27.22dB, the average is 28.9dB.

4 Discussion

4.1 PSNR enhancement

Decreasing the emit angle of the panel light source can improve the PSNR. Table. 2 shows the PSNR of different emitting angles at different distances.

Table. 2 PSNR of different emitting angles at different depth

PSNR	Emitting angle 0 ~ 5 degree	Emitting angle 0 ~ 10 degree	Emitting angle 0 ~ 15 degree	Emitting angle 0 ~ 20 degree	Emitting angle 0 ~ 25 degree
z = 200mm ("A")	39.60	35.62	32.62	31.65	31.65
z = 105.37mm ("B")	35.73	31.92	28.87	27.82	27.82
z = 48mm ("C")	35.77	31.86	28.60	27.62	27.62

4.2 Viewing angle

The Viewing angle (Ω) [6] depends on the image acquisition. Since the light passes through the lens, it can only be within the image region of the corresponding lens, so the angle cannot exceed Ω, and the Ω formula is Eq. 3.

$$\tan\left(\frac{\Omega}{2}\right) = \frac{pitch\,length}{2\times focal\,legth} \qquad (3)$$

The lens array used by our Light-Field Display has pitch = 2mm, focal length = 8mm, and the viewing angle is 14.25 degrees after calculation. We also list the viewing angles of different combinations of pitch and focal length systems in table. 3.

Table. 3 Viewing angle of different lens array parameters

Pitch(mm)	Focal length(mm)	Viewing angle(degree)
2	4	28.07
2	8	14.25
2	16	7.15
4	8	28.07
1	8	7.15

4.3 Resolution

In our system, the focal length of the lens array is equal to the gap with the panel, so we have a resolution of 1/pitch = 1/(2mm) and a pixel density of 12.7ppi. The way to improve the resolution is to increase the pitch / focal length of the lens array, but this method will reduce the viewing angle.

4.4 Elemental image of pitch

If p/2f is increased, the viewing angle can be increased, but the resolution will be decreased, which can be adjusted for the usage environment. We tried to change the original pitch = 2mm to 1mm and 4mm, and the result of the elemental image is as shown in Fig. 6 and Fig. 7.

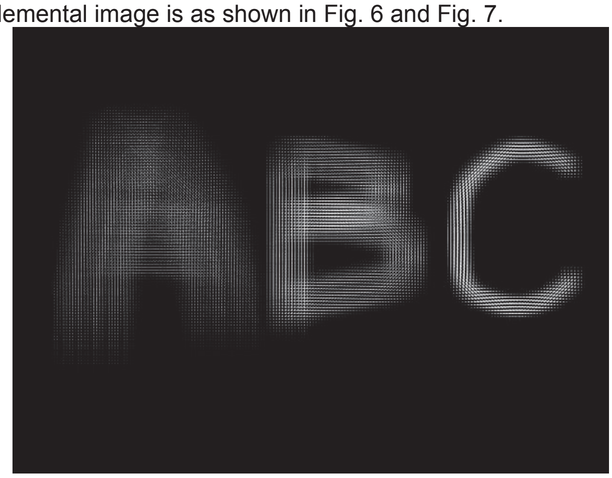


Fig. 6 elemental image of pitch = 1mm

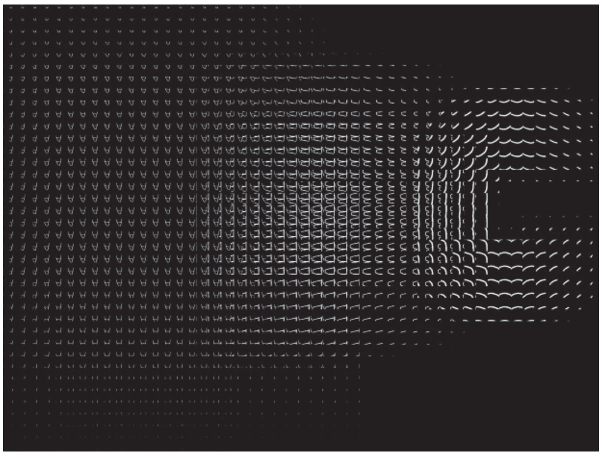


Fig. 7 elemental image of pitch = 4mm

5 Conclusions

After matching the 2D image with its depth and calculating with the CGEI algorithm, we can get the elemental image that stores the light field information. Using the integrated imaging based light field display with corresponding parameters to display the elemental image, we can restore the image with depth information. In our set parameters, the PSNR is 28.9dB on average, viewing angle is 14.25-degree, pixel density is 12.7ppi. Finally, we can achieve floating image, and VAC free naked-eye 3D experience.

Acknowledgement

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References

[1] Marc Levoy, and Pat Hanrahan. "Light field rendering." Proceedings of the 23rd annual conference on Computer graphics and interactive techniques. (1996)

[2] Manuel Martínez-Corral and Bahram Javidi, "Fundamentals of 3D imaging and displays: a tutorial on integral imaging, light-field, and plenoptic systems," Adv. Opt. Photon. 10, 512-566 (2018)

[3] Jae-Hyeung Park, Yunhee Kim, Joohwan Kim, Sung-Wook Min, and Byoungho Lee, "Three-dimensional display scheme based on integral imaging with three-dimensional information processing," Opt. Express 12, 6020-6032 (2004)

[4] N. Balram and I. Tosic, “Light-Field Imaging and Display Systems,” J. Inf. Disp. 32(4), 6–13 (2016).

[5] Se-Chan Oh, Ji-Soo Hong, Jae-Hyeung Park, and Byoung-Ho Lee, "Efficient Algorithms to Generate Elemental Images in Integral Imaging," J. Opt. Soc. Korea 8, 115-121 (2004)

[6] Sung-Wook Min et al, “New Characteristic Equation of Three-Dimensional Integral Imaging System and its Applications,” Jpn. J. Appl. Phys. 44 L71 (2005)