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Extended Fractional View Integral Photography Using Slanted Orthogonal Lenticular Lenses

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Abstract **–** Integral photography (IP) is one of the best 3D image display systems because both horizontal and vertical parallaxes can be obtained without a need to wear stereo glasses. IP hardware can most easily be produced by placing a fly's eye lens on a high-definition flat panel display, such as a liquid crystal display (LCD). The price of high-definition LCDs is falling given the progress of its production technology. By contrast, the initial cost of producing a fly's eye lens remains very high because a very expensive metal mold has to be produced in most cases. This problem has been solved by introducing the extended fractional view method, which enables the combination of any ready-made LCD with any ready-made fly's eye lens. However, other problems persist, i.e., the limited types of ready-made fly's eye lens on the market and the lack of large fly's eye lenses. Without such lenses, the 3D display screen size cannot be enlarged. In this work, we solved this problem by replacing a fly's eye lens with two mutually perpendicular lenticular lenses based on the fact that two orthogonally stacked lenticular lenses work as if they were a single fly's eye lens. Unlike fly's eye lenses, large off-the-shelf lenticular lenses are available in the market because of their applications in large 3D signboards, among others. Another issue to be addresses is the suppression of very obstructive moiré pattern caused by the interference between the LCD of pixels and small convex lenses. This problem was solved by slightly tilting the orthogonal fly's eye lenses against the LCD. In our experiment, a 3D scene data created with The Persistence of Vision Raytracer (POV-Ray) was rendered from 16 × 16 different viewpoints so that 256 still images were obtained. Our original software, which was developed in C# language, synthesized an IP image from the 256 images. When the image was displayed on a 4K 28-inch LCD and observed through the orthogonal lenticular lenses, a 3D image with both horizontal and vertical parallaxes was observed.

Keywords**:** 3D display, autostereoscopic, integral photography, slanted lenticular, fractional view

1. Introduction

The sense of depth caused by binocular parallax brings about a high sense of reality. Accordingly, various 3D displays have been proposed to date. Among them, the integral photography (IP), proposed by Lippmann in 1908 [1] is one of the best because both horizontal and vertical parallaxes are obtained without a need to wear stereo glasses. If an IP display is placed flat on a desk or on the floor, it can be viewed from any of the surrounding directions. However, compared with other autostereoscopic systems such as the lenticular system or the parallax barrier system (both of which cause parallax only on the horizontal direction), IP remains unpopular probably because IP of the following limitations: 1) the initial cost to produce a fly's eye lens is high (at least several tens of thousands of US dollars), 2) off-the-shelf large fly's lenses are unavailable; and 3) offensive moires sometimes occur. In this work, we present ways to settle these problems.

2. Technologies Used in Our System

We developed a new system that combines the technologies of fractional view system, orthogonal lenticular system, and slanted lenticular system.

2.1. Fractional View System

In autostereoscopic displays whose lenticular lenses are placed on this side of a liquid crystal display (LCD), the number of views is equal to the number of pixels per tiny semicylindrical lenses, as shown in Fig. 1(i). If the lenticular lens is designed and produced based on the LCD dimensions, the number of views can be made an integer precisely. Conversely, when an off-the-shelf LCD is combined with an off-the-shelf lenticular lens, the probability that the number of views becomes an integral by chance is almost zero. In most cases, the number of view becomes a non-integer, i.e., "fractional", as shown in

Fig. 1(ii). Even in this case, the path of light emitted from each pixel of the LCD and refracted by the lenticular lens is exactly calculable by using an algorithm similar to the ray-tracing method. Therefore, such a combination can also be used to produce a 3D display. This idea is basic for the fractional view method [2][3] proposed by Ishii. Yanaka [4][5] extended Ishii's method so that it can be applied to the IP, in which a disparity exists in both vertical and horizontal directions. This method is called the extended fractional view (EFV) method, which has also been adopted in the system described in this paper.

3 pixels per lens pitch.
3 is an integer.

(i) Example of integer view.

3.3 pixels per lens pitch.
3.3 is a non-integer.

(ii) Example of fractional view.

Fig. 1: Integer and fractional views.

2.2. Orthogonal Lenticular System

Owing to the EFV method, inexpensive ready-made lenticular lenses can be used, which greatly reduces the initial cost. However, other problems persist, i.e., the limited types of ready-made fly's eye lens on the market and the lack of large fly's eye lenses. Without such lenses, the 3D display screen size cannot be enlarged. In this work, we solved this problem by replacing a fly's eye lens with two mutually perpendicular lenticular lenses, as shown in Fig. 1[4] based on the fact that two orthogonally stacked lenticular lenses work as if they were a single fly's eye lens. Unlike fly's eye lenses, large off-the-shelf lenticular lenses are available in the market because of their applications in large 3D signboards, among others.

2.3. Slanted Lenticular System

In the lenticular system, which causes a parallax only in the horizontal direction, the number of views can be increased by tilting the lenticular lens against the LCD. A patent of Philips [6] is related to this technique, i.e., tilting to certain angles to obtain the certain number of viewpoints. Conversely, in the case of fractional view, the purpose of tilting the lenticular lens is not to increase the number of viewpoints because the number of viewpoints is infinite from the beginning. The purpose of tilting, as shown in Fig. 3, is to reduce moirés [7][8][9]. In this case, we have considerable latitude in the angle of tilt permitted in this case. We set the angle to 10° in our experiment, but wide-range angles can be chosen.

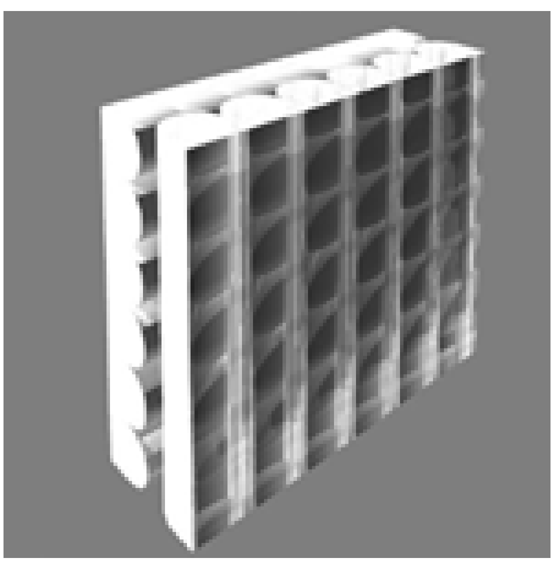

Fig. 2: Normal orthogonal lenticular lenses (normal mutually perpendicular lenticular lenses).

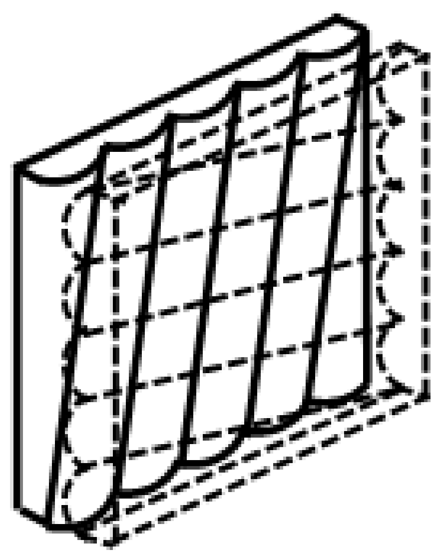

Fig. 3: Slanted orthogonal lenticular lenses (slanted mutually perpendicular lenticular lenses).

3. Experiment

3.1. System used for the experiment

Fig. 4 shows the system configuration.

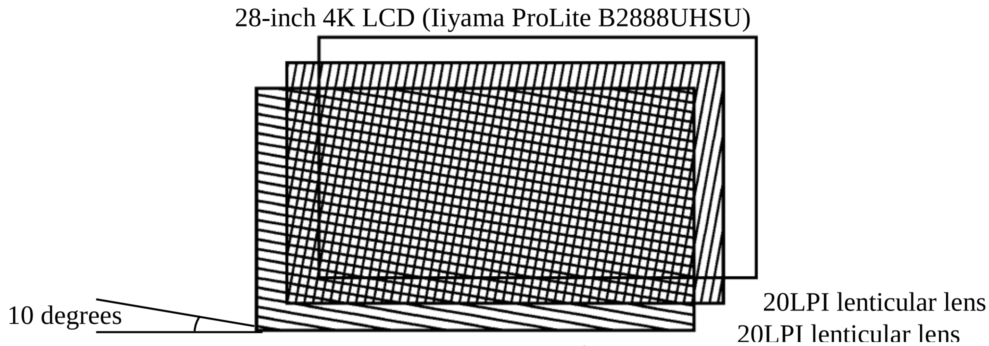

Fig. 4: System configuration.

3.2. Rendering of Multi-viewpoint Images

A 3D scene data created with the Persistence of Vision Raytracer (POV-Ray) was rendered from 16 × 16 different viewpoints so that 256 still images are obtained, as shown in Fig. 5.

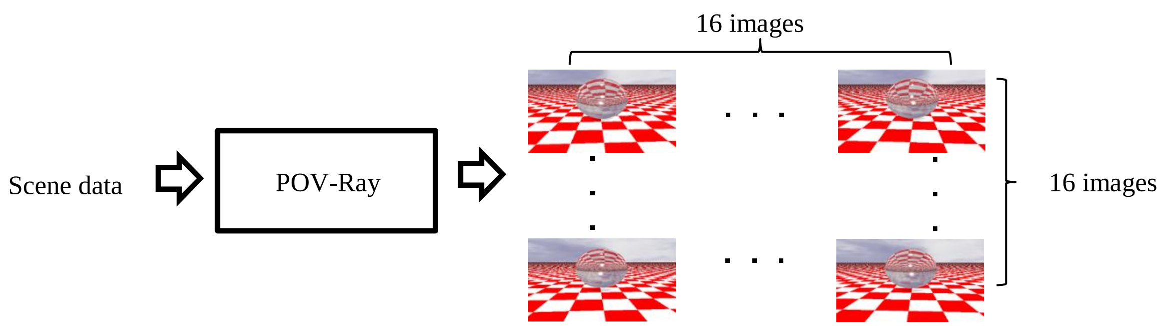

Fig. 5: Rendering of Multi-viewpoint Images.

3.3. Synthesis of IP Image

Our original software, which was developed in C# language and is shown in Fig. 6, was used to synthesize an IP image from the 256 images. First, the coordinates of all the subpixels on the screen are converted from the (x, y) into the (X, Y) based on the following formula, where (x, y) are the coordinates of a subpixel of the coordinate system of the LCD, and (X, Y) are the coordinates of the coordinate system of the lenticular lenses, as shown in Fig. 7. In both cases, units are subpixel.

$$\mathrm{X} = \mathrm{x}\cos\theta + y\sin\theta$$

$$\mathrm{Y} = -\mathrm{x}\sin\theta + y\cos\theta$$

Second, values of x and y are quantized by the width of the small cylindrical lens, thereby revealing the elemental image to which the subpixel belongs. At the same time, the coordinates of the center of the elemental image (X_c, Y_c) can be obtained. Accordingly, (X_c, Y_c) are converted to (x_c, y_c) based on the following formula.

$$x_c = X_c\cos\theta - Y_c\sin\theta$$

$$y_c = X_c\sin\theta + Y_c\cos\theta$$

Notably, both (x, y) and (x_c, y_c) are the coordinates of the screen coordinate system considering that the vector (x_c -x, y_c -y) denotes the vector from the subpixel to the center of the elemental image to which the subpixel belongs. This value denotes the direction of light emitted from the subpixel. Therefore, based on this value, an image is chosen among the 256 still images, and the value of the corresponding subpixel of the image is set to the subpixel of the IP image. This procedure is repeated for all of subpixels of the IP image until this image is completed.

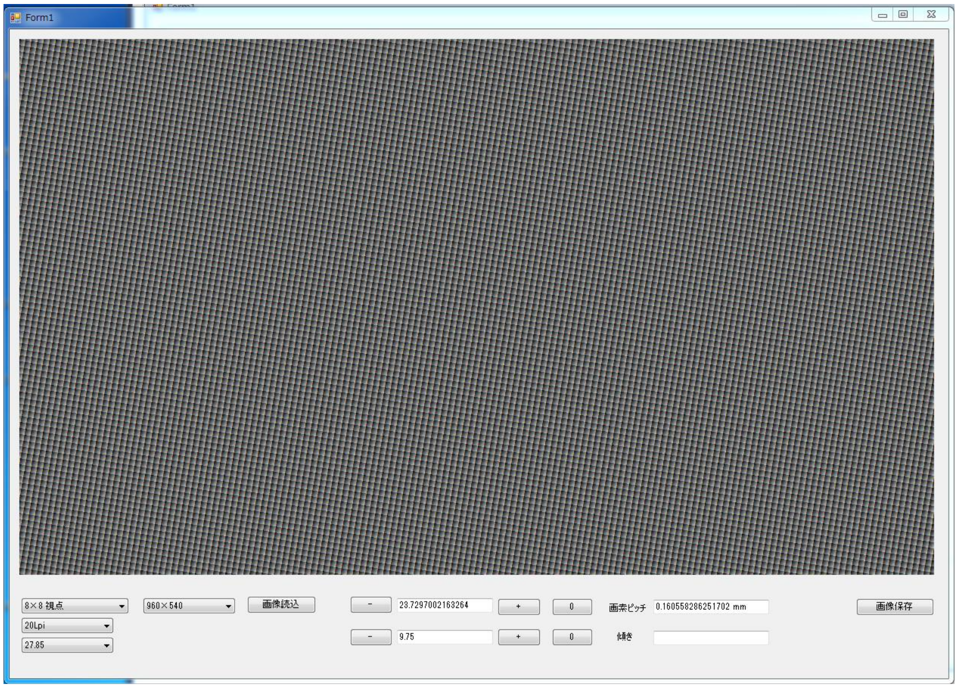

Fig. 6: Screenshot of our original software.

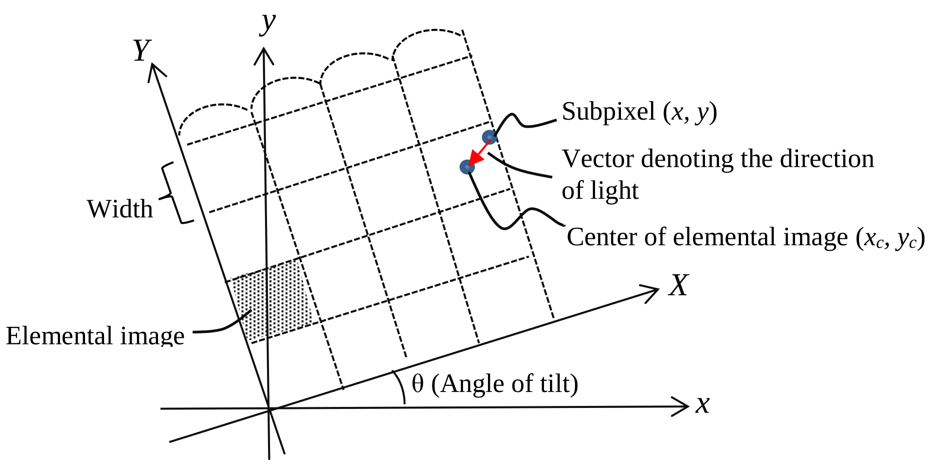

Fig. 7: Coordinate system of LCD (*xy*) and coordinate system of lenticular lens (*XY*).

4. Results

Fig. 8 shows a synthesized IP image. When a part of it is magnified, elemental images become visible. Fig. 9 shows images, displayed with our experimental system, which are viewed from various positions.

5. Conclusion

A new IP system combining three technologies (the EFV system, the orthogonal lenticular system, and the slanted lenticular system) was developed. Given that the EFV system was adopted, inexpensive off-the-shelf lens can be used. Moreover, considering the adoption of the orthogonal (or perpendicular) lenticular system, enlarging the screen size is easy because various ready-made large lenticular lenses are available in the market. Moreover, offensive moiré pattern is suppressed by slightly tilting the lenticular lenses to the LCD. Therefore, the method proposed in this paper is suitable for the single or small-scale production of large autostereoscopic displays using IP, which has been difficult up until now. The proposed scheme can also expand the use of digital signage with IP, for example.

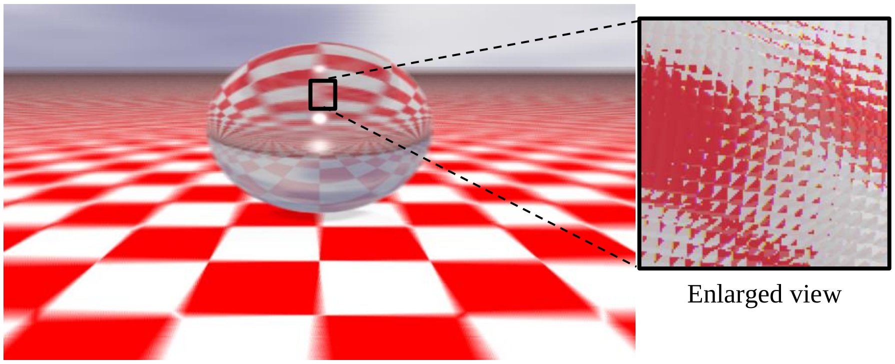

Fig. 8: Synthesized image.

Fig. 9: Image viewed from various positions.

Acknowledgements

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References

[1] G. Lippmann, “Épreuvestréversibles donnant la sensation du relief,” *J. Phys. Theor. Appl.*, vol. 7, pp.821-825, 1908.

[2] M. Ishii, “Fractional View 3D Display,” *3D Image Conference 2004*, pp.65-68, 2004 (in Japanese).

[3] M. Ishii, “Spacial Image by Fractional View Display,” *ITE Technical Report*, vol. 30, no. 58, pp. 33-38, 2006 (in Japanese).

[4] K. Yanaka, “Integral photography suitable for small-lot production using mutually perpendicular lenticular sheets and fractional view,” in *Proc. SPIE 6490, Stereoscopic Displays and Virtual Reality Systems XIV*, 2007, 9 pages.

[5] “Integral Photography using Hexagonal Fly’s Eye Lens and Fractional View,” in *Proc. SPIE 6803, Stereoscopic Displays and Applications XIX*, 2008, 8 pages.

[6] C. V. Berkel and J. A. Clarke, “Autostereoscopic display apparatus,” U.S. Patent 6,064,424, May 16, 2000.

[7] Y. Kim, G. Park, S.-W. Cho, J.-h. Jung, B. Lee, Y. Choi, and M.-G. Lee, “Integral imaging with reduced color moire pattern by using a slanted lens array,” in *Proc. SPIE 6803, Stereoscopic Displays and Applications XIX*, 8 pages, 2008.

[8] Y. Kim, G. Park, J.-H. Jung, J. Kim, and B. Lee, “Color moiré pattern simulation and analysis in three-dimensional integral imaging for finding the moiré-reduced tilted angle of a lens array,” *Applied Optics*, vol. 48, no. 11, pp. 2178–2187, 2009.

[9] K. Yanaka and K. Uehira, “P-9: Extended Fractional View Integral Imaging Using Slanted Fly’s Eye Lens,” *SID Symposium Digest of Technical Papers*, vol. 42, no. 1, pp. 1124–1127, 2011.