360-Degree Autostereoscopic Display using Conical Mirror and Integral Photography Technology

Nobuyuki Ikeya and Kazuhisa Yanaka
Kanagawa Institute of Technology, Atsugi, Japan

Keywords: 360 Degrees, Autostereoscopic, Conical Mirror, Integral Photography.

Abstract: We propose a new 360° autostereoscopic display that combines a conical mirror and integral photography technology. Our system is similar to the conventional holographic pyramid in that a 3D object appears to float near the center. However, the pyramid consists of four planes with visible borders, whereas the conical mirror only has a seamless curved surface. Therefore, a stereoscopic image can be observed from any angle. The object displayed in the cone is a CG character. It is pre-rendered every 0.5° to obtain 720 still images. One IP image is synthesized based on those still images. This system has the advantage of being manufactured at a relatively low cost. Moreover, high reliability can be expected because this display has no mechanical moving parts.

1 INTRODUCTION

A 3D display that resembles a real object from any 360° direction is an ideal display, and it has been actively studied by researchers.

Jones et al. (2012) proposed a display that consists of a high-speed video projector, a spinning mirror covered by a holographic diffuser, and FPGA circuitry. Takaki et al. (2012) proposed a 360° 3D display with a table screen, which consists of a small number of high-speed projectors and a rotating screen. Xia et al. (2013) proposed a system using a high frame-rate projector and a flat light-field scanning screen and a revolving mechanism. In these studies, mechanical moving parts are used. Yoshida (2016) proposed a glasses-free tabletop 3D display in which virtual objects appear to be floating on a flat tabletop surface without using mechanical moving parts; instead, a large number of projectors are used.

As another approach, a holographic pyramid can be used to obtain a 360° field of view. In this method, a pyramid made of a translucent material is placed upside down on a flat display, and the image of the flat display is reflected on the surface of the pyramid for observation. In this case, if the image on the flat display is 2D, then the image in the pyramid is its mirror image. Therefore, the image is also 2D.

However, using integral photography (IP) instead of a flat panel display, the image that appears to be floating inside the pyramid can be turned into 3D.

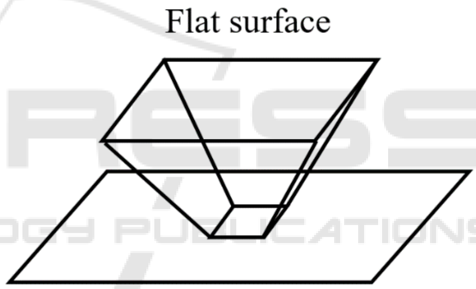

Figure 1: Conventional system using a pyramid.

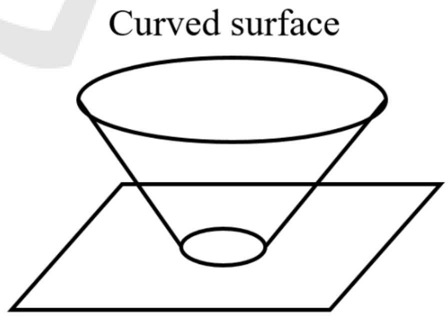

Figure 2: Our proposal using a conical mirror.

An autostereoscopic display that looks as if the object is floating inside a square pyramid can be created by combining a pyramid made of a material that reflects light with IP (Yamanouchi et al. 2016) (Anraku et al. 2018) However, as shown in Fig. 1, the quadrangular pyramid consists of four surfaces: front, back, left, and right. Therefore, the boundaries

Ikeya, N. and Yanaka, K.
360-Degree Autostereoscopic Display using Conical Mirror and Integral Photography Technology.
DOI: 10.5220/0009106208140818
In *Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2020) - Volume 4: VISAPP*, pages 814-818
ISBN: 978-989-758-402-2; ISSN: 2184-4321

between any two surfaces may be visible. We have developed a new system (Fig. 2) that uses only curved surfaces. The displayed object can be displayed in a 360° autostereoscopic view by using a cone instead of a square pyramid.

2 METHOD

The proposed system consists of two parts. One is an IP-type display in which a fly's eye lens is superimposed on a liquid crystal display (LCD) or an organic light-emitting diode display, and each pixel emits a light beam in a specific direction. The other is a conical mirror that reflects light coming from an IP display and directs the light in a 360° direction. The IP image synthesis method is important here. In conventional holographic pyramids, only four IP images corresponding to the front, rear, left, and right are synthesized. However, when using a conical mirror, this method becomes inapplicable because the surface is not a plane but is curved instead. Therefore, a new method that is similar to ray tracing described below is applied.

In general, light rays passing through the center of a transparent sphere travel straight without being refracted at the surface of the sphere.

Similarly, in a spherical lens, a ray passing through the center of curvature goes straight without being refracted.

As shown in Fig. 3, the light emitted from each pixel of the LCD is emitted to the space through a minute convex lens, which is part of a fly's eye lens. Moreover, the path of the light can be accurately calculated if the pixel pitch of the LCD and the lens pitch of the fly's eye lens are known.

In Fig. 3, assuming that the distance between the LCD and the fly's eye lens is the same as the focal length of each convex lens, the convex lens changes the light emitted from an LCD pixel into parallel rays. The direction of the light beam can be calculated using the property that a light beam passing through the center of curvature goes straight. Considering that light rays are refracted on the surface when exiting the fly's eye lens, the virtual pixel position is point P = (p_x, p_y, p_z), and the direction vector of the ray is u = (u_x, u_y, u_z). Here, the coordinate system is a rectangular one with the origin at the vertex below the cone.

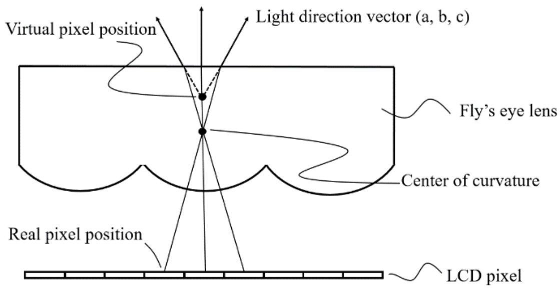

Figure 3: Path of light emitted from LCD pixels.

In Fig. 4, light emitted from point P on the fly's eye lens in the direction vector u is assumed to be reflected at point Q on the conical mirror and directed to the direction vector v.

The equation light emitted from point P is as follows, using t as a parameter.

$x = u_x \times t + p_x$

$y = u_y \times t + p_y$

$z = u_z \times t + p_z$

Meanwhile, the equation of the cone is as follows:

$x^2 + z^2 = y^2$.

By making these equations simultaneous, the point Q = (q_x, q_y, q_z) can be calculated, where the light meets the conical mirror and the direction of the reflected light.

Given that the normal of the conical surface at this intersection is $n = (n_x, n_y, n_z) = (q_x, q_y, -q_z)$, the direction vector $v = (v_x, v_y, v_z)$ of the reflected light can be obtained by Snell's law. Furthermore, the equation of the reflected light is as follows, where t is a parameter.

$x = v_x \times t + v_x$

$y = v_y \times t + v_y$

$z = v_z \times t + v_z$

A square is selected among 720 squares passing through the central axis of the conical mirror. The projection of the square onto the XY plane must be orthogonal to v. An image obtained by rendering an object from this direction is assumed texture-mapped in advance in this square. An image rendered from the direction closest to v is selected among 720 still images obtained by rendering an object from 720 directions. Proceeding from point Q in the direction of $-v$, point R intersects the square. Thus, the pixel value at such point is acquired and set as the value of pixel P on the LCD.

When this process is performed for all pixels on the LCD, one IP image is completed and displayed on the LCD.

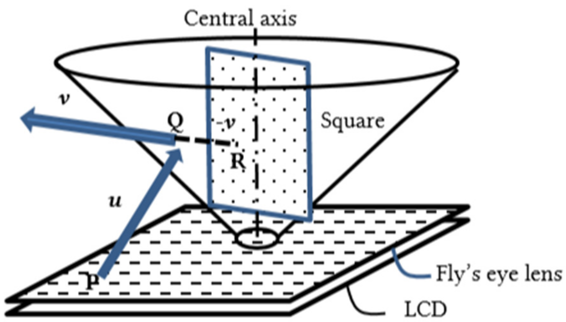

Figure 4: Principle of IP image synthesis.

The reason why stereoscopic display is possible with this system is as follows. In Fig. 5, the left eye looks at image A. The right eye sees image B. Here, images A and B are two of the 720 images obtained from 720 directions.

Accordingly, stereoscopic images can be obtained because the same subject seen from different viewpoints enters the left eye and the right eye.

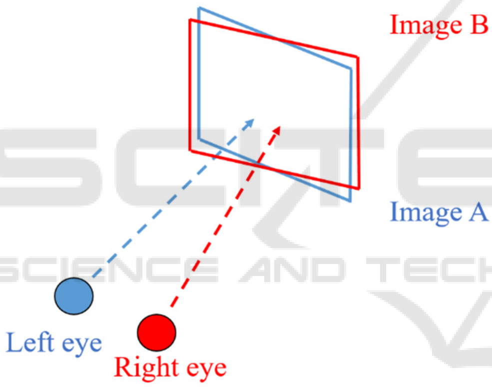

Figure 5: Reasons for stereoscopic viewing.

3 EXPERIMENTS

The experimental system consists of an IP-type display consisting of a laptop PC, fly's eye lens, and a conical mirror.

Microsoft Surface Book 2 is used as a laptop PC. Given that its LCD resolution is 2000 × 3000 and that the screen size is 13.5 inches diagonally, the pixel diagonal is 3065.5. Therefore, the resolution is 3065.5 / 13.5 = 227.1 dpi (dots per inch).

Fig. 6 shows the appearance of the used fly's eye lens. The shape is shown in Fig. 7. The distance between adjacent lenses, or lens pitch, is 2.35 mm, or 10.81 dpi. The number of LCD pixels per lens pitch is 271.8 / 10.81 = 25.14. Given that this value is not an integer, the extended partial view method (Yanaka 2008) is used to produce an IP image.

The LCD is combined with a coarse fly's eye lens, so the final resolution obtained is determined by the fly's eye lens. In this system, the final resolution is 10.81 dpi.

The conical mirror shown in Fig. 8 is made of stainless steel and has an exterior mirror finish.

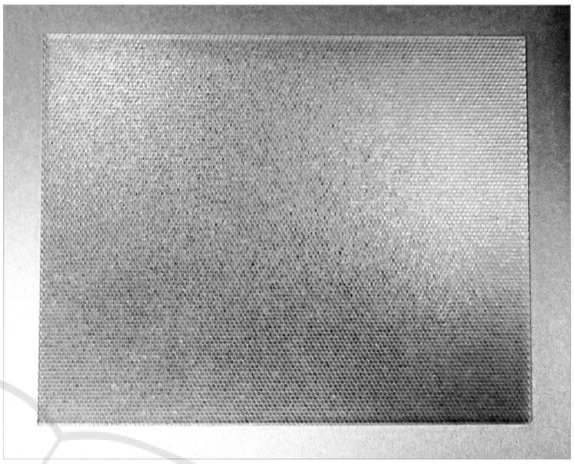

Figure 6: Fly's eye lens.

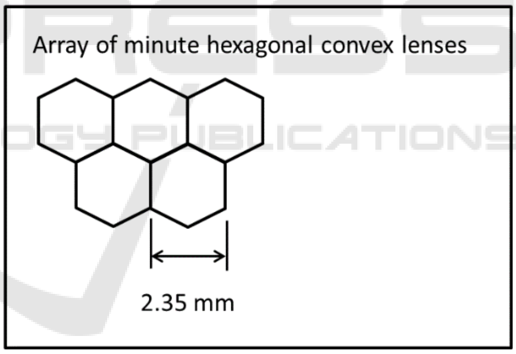

Figure 7: Shape of the fly's eye lens used.

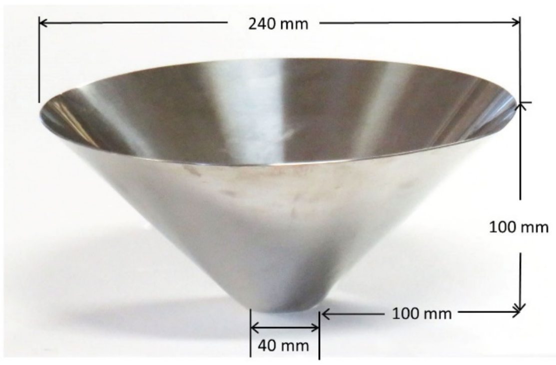

Figure 8: Conical mirror.

Unity-chan, a CG character provided by Unity Technologies Japan, is used as a 3D object to be displayed in a conical mirror. As shown in Fig. 9, Unity-chan has been pre-rendered in 360° increments every 0.5°, and 720 still images are obtained.

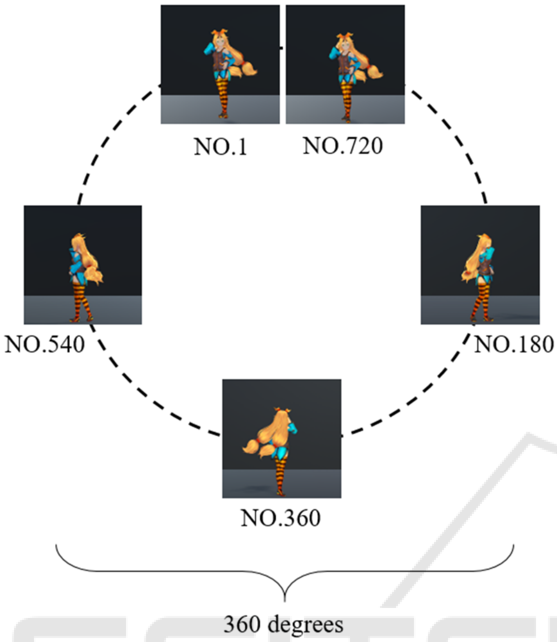

Figure 9: Pre-rendered images (© UTJ/UCL).

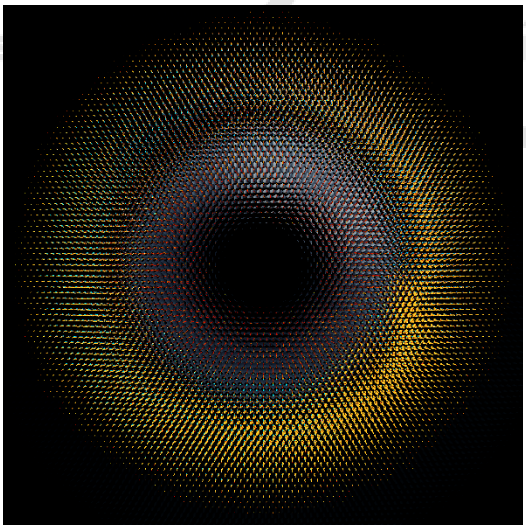

Figure 10: Finished IP image to be displayed on the LCD of Microsoft Surface Book 2 with a resolution of 2000 × 2000 pixels (Only the central part of the 2000 × 3000 pixel LCD is used.).

Subsequently, an IP image (Fig. 10) is synthesized using the method described in the previous chapter. Unlike a normal IP image, the synthesized image has an annular pattern because it corresponds to 360°.

Fig. 11 shows an example of an autostereoscopic image displayed by a system on a turntable. Our system does not include mechanically moving parts. The turntable is used only for shooting videos.

When this system is placed and observed on an electric turntable, the autostereoscopic image can be seen in any direction from any angle. However, the current 3D image that appears inside the cone is unclear. This problem will be improved in the future by using high-resolution LCDs and fine fly's eye lenses.

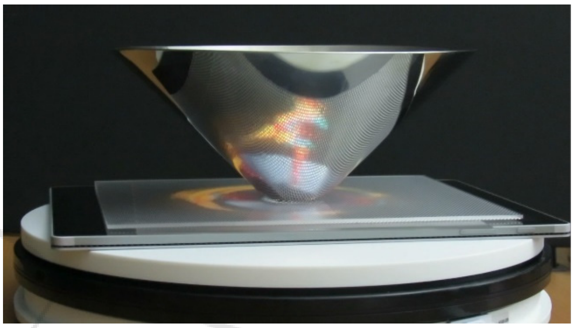

Figure 11: Autostereoscopic image displayed with our system on an electric turntable (© UTJ/UCL).

4 CONCLUSIONS

A new 360° autostereoscopic display is proposed. The hardware of this system is simple, with a conical mirror added to a conventional IP display. Therefore, this system has the advantage of being manufactured at a relatively low cost. Moreover, high reliability can be expected because this display has no mechanical moving parts.

At present, the displayed 3D objects are not very clear. If high-resolution LCDs and fine, wide-angle fly's eye lenses are available in the future, then improvements are expected. Another issue is that the stereoscopic image is not animating but still.

However, when each frame of the animation is created as an IP image, and the IP images are connected together, an autostereoscopic animation can be created. In addition, the parallax is only in the horizontal direction, but it can be extended to add the vertical parallax in principle. We will examine these extensions in the future.

REFERENCES

Anraku, S., Yamanouchi, T., Yanaka, K., (2018). Real-time Integral Photography Holographic Pyramid using a Game Engine.In *VISIGRAPP 2018 - Volume 4: VISAPP*, pp. 603 - 607.

Jones, A., McDowall, I., Yamada, H., Bolas, M., Debevec, P., (2007). Rendering for an interactive 360° light field display. In *SIGGRAPH 2007 Papers Proceedings*.

Takaki, Y., Uchida, S., (2012). Table screen 360-degree three-dimensional display using a small array of high-speed projectors. In *Optics Express* Vol. 20, Issue 8, pp. 8848-8861.

Xia, X., Liu, X., Li, H., Zheng, Z., Wang, H., Peng, Y., Shen, W., (2013). A 360-degree floating 3D display based on light field regeneration. In *Optics Express* Vol. 21, Issue 9, pp. 11237-11247.

Yamanouchi, T., Maki, N., Yanaka, K., (2016). Holographic Pyramid Using Integral Photography. In *The 2nd World Congress on Electrical Engineering and Computer Systems and Science*.

Yanaka, K. (2008). Integral photography using hexagonal fly's eye lens and fractional view. In *Proceedings Volume 6803, Stereoscopic Displays and Applications XIX; 68031K*, 8 pages.

Yoshida, S., (2016). fVisiOn: 360-degree viewable glasses-free tabletop 3D display composed of conical screen and modular projector arrays. In *Optics Express* Vol. 24, Issue 12, pp. 13194-13203.