

# 3D Display System Using High Resolution Transparent Printer Output

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## Abstract

This paper proposes a 3D display system which consists of two transparent films, a transparent plate and an illumination. Special patterns are printed on the films by a high resolution printer. This system is a simplified version of integral photography. A part of two-dimensionally high resolution of the printer is diverted toward the third dimension, namely the depth. Accordingly, the resolution of depth direction becomes high, as the resolution of the printer is high. 3D image information can be generated with a method that is similar to the ray tracing of computer graphics. Viewers can see colored 3D figures from optional direction. Although this system resembles holography in this point, such high resolution as holography is not demanded from printers. By experiments in which an inexpensive ink jet printer is used, it has been confirmed that fine 3D images can be displayed.

## Introduction

In recent years, various researches on three dimension display systems<sup>1,2</sup> have been reported. Among many clues of our depth perception, binocular parallax gives the most powerful sense of depth. Since our eyes are around 6-6.5 cm apart, the images on our two retinas are slightly different, owing to the difference of viewpoints. The difference of the two images is called parallax, and it is regarded to be the most important clue of our stereoscopic perception.

Anaglyph is a well-known system in which one image is printed in red and the other in blue, and you view the images simultaneously through special glasses, with red filter for one eye and blue filter for the other. Vectorgraph is a more sophisticated system that is based on the optical phenomenon of polarization. The limitation of these systems is that viewers have to wear special glasses with colored or polarized filters.

An autostereoscopic system is one in which the viewer can perceive the image with full parallax without any kind of optical aid or visual training. In parallax stereograms the viewer perceive a composite image through interstices of a vertical opaque bars. On the composite image, the left eye image and the right eye image have been merged alternatively as vertical strips. A more modern version of this uses lenticular lenses instead of the bars. It is also

possible to extend this system by increasing the number of images so that more than two viewpoints are allowed. However, this system presents horizontal parallax only.

The two dimensional version of the parallax stereograms is the integral photography, in which fry-eye lenses are used instead of the lenticular lenses.

In conventional integral photography systems, special fly-eye lenses, machines, and printing technology are used. In this research, a similar system has been realized by using an inexpensive PC and a printer.

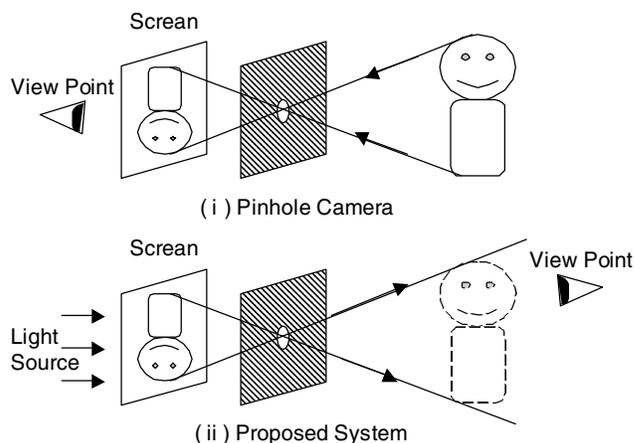


Figure 1. Principles

## Proposed System

Figure 1 shows the principle of conventional pinhole cameras and our system. In pinhole cameras, light which leaves an object passes through a hole, and gets to a screen, on which a real image are generated. To the contrary, in the proposed system, light leaves a screen, go through a hole, and gets to the viewpoint. If the number of hole is only one as shown in Figure 1, only a point of 3D objects can be seen. However, if many holes are arranged like an array, rays of light from holes concentrate at certain points in a 3D space, so that complete 3D objects are observed.

Two transparent OHP sheets are used in this research as shown in Figure 2.

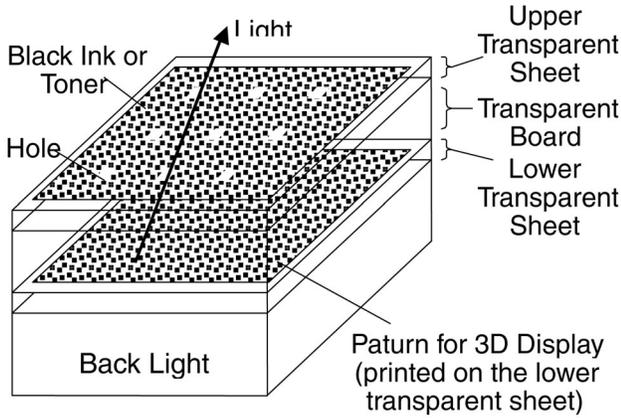


Figure 2. Proposed System

The upper transparent sheet is the substitute of the fly-eye lens in IP. Only the grid points of the sheet remain transparent. Other parts of the sheet are covered by black ink so that light does not go through the sheet. On the lower transparent sheet, special image data are printed. By putting a transparent acrylic board between the two transparent sheets, the intervals between two sheets are kept regularly. By illuminating the sheets from the bottom by a back light, a 3D image can be displayed.

The principle of the proposed system is similar to that of pinhole cameras, or ray tracing method that is used in Computer Graphics. The light that went out from the lower sheet reaches to a viewpoint through the hole. Viewers feel the light as if it comes from the object that exists in the three dimensional space.

As shown in Figures 3 and 4, we use a coordinates system in which the starting point is the lower left corner of the lower sheet and the distance between adjacent picture elements is one. Rays of light which are emitted from  $M \times M$  pixels go through a hole, the position of which is the center of the pixels. Therefore, the coordinates of the position of the hole are  $((M - 1)/2, (M - 1)/2, c)$ . Where  $C$  is the thickness of the transparent board. On the other hand, the coordinates of a picture element that we are paying attention to are  $(k, j, 0)$ . In this case, the direction of the straight line from the pixel to the hole is expressed by the following vector  $(a, b, c)$

$$(a, b, c) = \{ (M - 1)/2 - k, (M - 1)/2 - j, c \} \quad (1)$$

In general, equations of a straight line, which goes through the point  $(x_0, y_0, z_0)$  and direction of the line is expressed by the vector  $(a, b, c)$ , are shown as follows,

$$\begin{aligned} x &= x_0 + at \\ y &= y_0 + bt \\ z &= z_0 + ct \end{aligned} \quad (2)$$

where  $t$  is a parameter. Strictly speaking, the refractive index of the transparent board is greater than one. Therefore, the light is refracted. However we suppose that the

refraction index is one so as to simplify the discussion, and no refraction occurs. In this case, the light from the hole goes straight without changing direction. When (1) is substituted for (2) the equation of the straight line which goes through the picture element and the hole is obtained. This straight line and the object, which is placed in three dimensional space as shown in Figure 3, not always meet. If they meet, the number of points of intersection is usually more than one, so that a point of intersection which is closest to the view point is chosen. The color of the picture element on the lower sheet is set to the color of the surface at the point of intersection. If they do not meet, the color of the picture element is the background color.

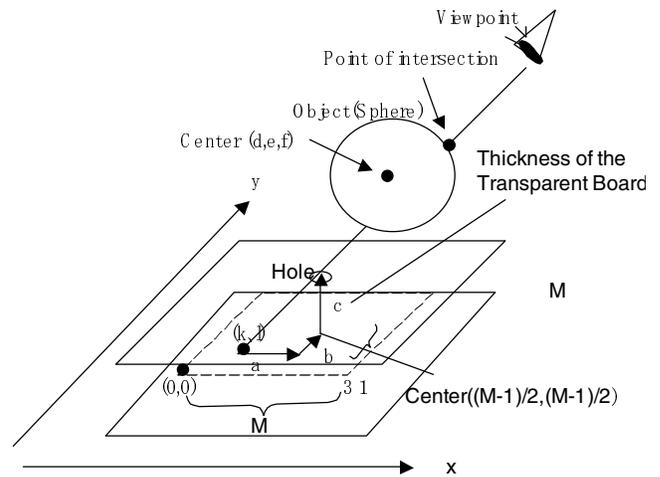


Figure 3. Coordinate System

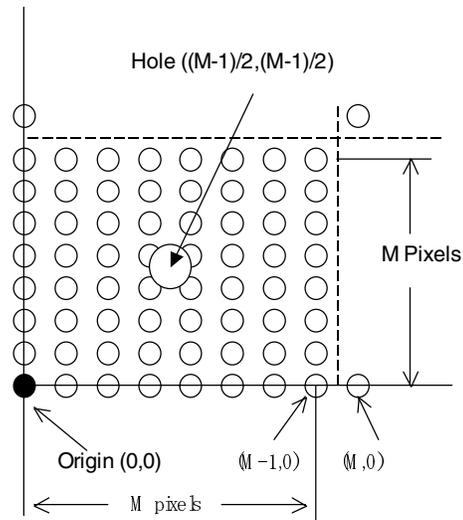


Figure 4. Coordinate System (top view)

It is not easy however to calculate the point of intersection if the figure of the object is not simple. In order to simplify the discussion, let us assume all the objects are spheres. Suppose the coordinates of the center are  $(d, e, f)$ .

Then the equation of the sphere is

$$(x - d)^2 + (y - e)^2 + (z - f)^2 = r^2 \quad (3)$$

When (2) is substituted for (3),

$$\begin{aligned} & a^2 t^2 + b^2 t^2 + c^2 t^2 + 2at(x_0 - d) \\ & + 2bt(y_0 - e) + 2ct(z_0 - f) + (x_0 - d)^2 \\ & + (y_0 - e)^2 + (z_0 - f)^2 = r^2 \end{aligned} \quad (4)$$

This is a second order polynomial expression regarding  $t$ , so that it can be arranged according to the order of  $t$ .

$$\begin{aligned} & (a^2 + b^2 + c^2)t^2 + \{2a(x_0 - d) \\ & + 2b(y_0 - e) + 2c(z_0 - f)\}t + (x_0 - d)^2 \\ & + (y_0 - e)^2 + (z_0 - f)^2 = r^2 \end{aligned} \quad (5)$$

Let us define variables  $U, V, W$  as follows.

$$U = a^2 + b^2 + c^2 \quad (6)$$

$$V = t^2 + a(x_0 - d) + b(y_0 - e) + c(z_0 - f) \quad (7)$$

$$W = (x_0 - d)^2 + (y_0 - e)^2 + (z_0 - f)^2 - r^2 \quad (8)$$

Then, equation (5) is expressed by

$$Ut = 2Vt + W = 0 \quad (9)$$

According to the relation between coefficients and roots of second order polynomial expression, the straight line and the sphere meets if

$$V^2 - UW \geq 0 \quad (10)$$

As mentioned above, this technique used to generate the 3D images is similar to "Ray Tracing", which is popular in Computer Graphics. The difference is that the tracing starts from picture elements on the lower sheet, instead of the viewpoint. Therefore we call our method "Inverse Ray Tracing".

## Experiments

Following devices are used in this experiment.

Printing System: Inkjet Color Printer (EPSON PM800C)

Backlight: Fiji Film Color Illuminator

Film: OHP sheets for EPSON Ink Jet Printers (EPSON MJOHPS1N)

Transparent Board: acrylic boards

The following program is used.

Program: Original program written in Microsoft Visual C++  
Following parameters are used.

$M$  is the number of pixels between holes, and is 32.

The resolution of the printer output is 360 dpi. Therefore, the pixel size is

$$\begin{aligned} & 25.4[\text{mm/inch}]/360[\text{dot/inch}] \\ & = 0.0706[\text{mm/dot}] \end{aligned} \quad (11)$$

$c$  is the thickness of a transparent board, the unit of which must be pixel, or dot. Since the thickness is 3mm,

$$c = 3[\text{mm}]/0.0706[\text{mm/dot}] = 42.5[\text{dot}] \quad (12)$$

The viewing angle, which is the range in which viewers can see the 3D image, is

$$\begin{aligned} & 2\tan^{-1}((M - 1)/(2c)) = 2\tan^{-1}(31/(2 \times 42.5)) \\ & = 2\tan^{-1}(0.365) = 2 \times 20 = 40\text{deg rees} \end{aligned} \quad (13)$$

Figure 5 is a pattern printed on a upper transparent sheet. Figure 6 is a pattern printed on a lower transparent sheet. Figure 7 and Figure 8 are the virtual spheres which appear on the 3D space. If you move the position of the eyes, different images can be seen.

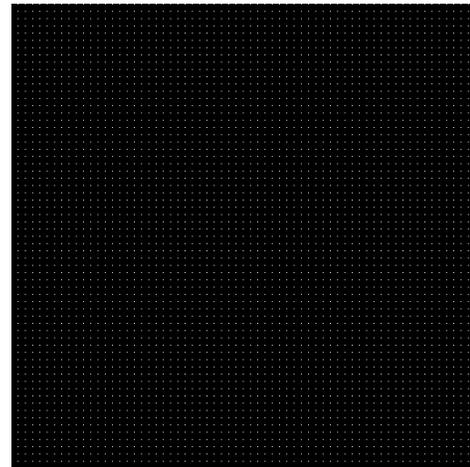


Figure 5. Pattern printed on a upper transparent sheet

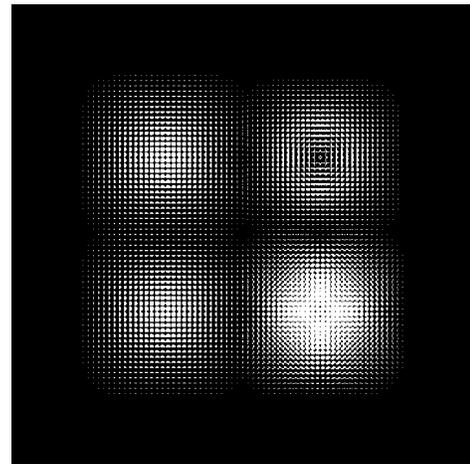


Figure 6. Pattern printed on a lower transparent sheet

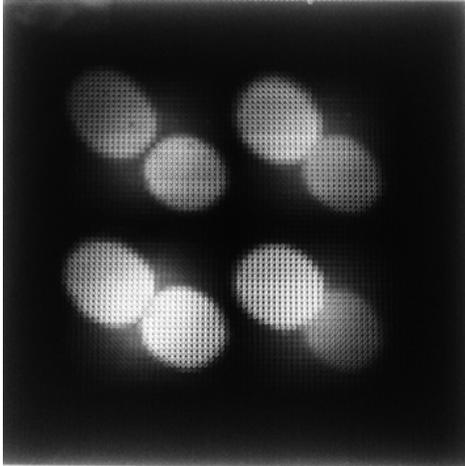


Figure 7. Virtual spheres which appear on the 3D space<sup>1</sup>

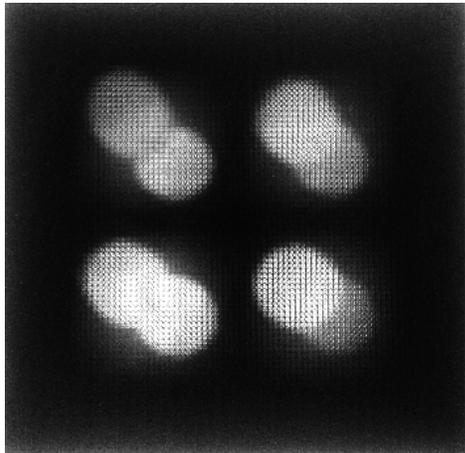


Figure 8. virtual spheres which appear in the 3D space<sup>2</sup>

## Conclusion

A new 3D display system has been proposed. Through experiments it has been made sure that 3D objects can be displayed. As the resolution of printers increases, the picture quality would be increased as well.

## References

1. Graham Saxby, The Science of Imaging An Introduction, Institute of Physics Publishing, Bristol, UK, 2002.
2. John C. Russ, The Image Processing Handbook 2nd Edition, CRC Press, Boca Raton, FL, 1995.

## Biography

**Susumu Sasaki** received his BE degree in Information Technology from Kanagawa Institute of Technology, Japan, in 2001. He is a graduate school student of Kanagawa Institute of Technology. His research interests include 3D image processing and multimedia communication.

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