Image Synthesis Method for Integral Photography Using Hexagonal Fly's Eye Lens

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Abstract

A new method of synthesizing an image is presented, which is essential for integral photography, using high-resolution printer output and a fly's eye lens sheet. Integral photography (IP) is one of the best stereoscopic viewing systems available because not only horizontal but also full parallax can be obtained without the need for wearing special glasses. A special image, called an IP image, is synthesized with a computer using this technology, and is output with a high-resolution printer. When the image is observed through a special lens sheet, called a fly's eye lens, superb binocular vision can be obtained. The lens sheet consists of an array of minute convex lenses. Each lens is either square or hexagonal and the latter has the advantage that the number of lenses for each unit area can be increased. However, the existing method of synthesis is no longer applicable. Therefore, we propose a method of synthesis that can be applied to these cases. Half the proposed method is the same as the existing one in which hundreds of still images are taken with a real or virtual camera from different angles. However, the next stage of the method is only for cases using the hexagonal fly's eye lens. The displacement from the center of the nearest hexagonal lens is calculated for all pixels of in the IP image. Since the displacement corresponds to the direction of a ray emitted from a pixel, the nearest camera position to the ray is calculated from hundreds of camera positions. A pixel position that corresponds to the hexagonal lens is calculated from the image taken from the camera position, and the pixel value is set to the pixel of the IP image. Finally, the IP image is scaled to the final IP image so that the size matches the hexagonal fly's eye lens sheet. Experiments demonstrated that excellent binocular vision could be obtained using the new method.

Introduction

Three-dimensional printing with binocular vision is very promising because one of the methods of making the most of the ultra-high resolution of the most advanced printers is to allocate it in the direction of depth. Integral photography (IP)[1][2] is one of the best stereoscopic viewing systems because not only horizontal parallax but also full parallax can be obtained without the need for wearing special glasses. A special image, called an IP image, is synthesized with a computer for binocular vision and is output with a high-resolution printer using this technology. Superb binocular vision can be obtained when the image is observed through a special lens sheet, called a fly's eye lens. There are numerous minute convex lenses on a transparent board in the fly's eye lens formed in an array.

As can be seen from in Figure 1, the convex lenses are either square or hexagonal. The latter has the advantage that the number of lenses for each unit area can be increased. If the lens is square, the IP image can be synthesized relatively easily because images are usually sampled with a square grid and because the camera position is also on a square grid. Synthesis is not simple, on the other hand, if the lens is hexagonal. Another problem is that the period of the lens, in other words, the distance between two adjacent lenses, depends on the horizontal or vertical direction. The ratio between the horizontal and the vertical periods is also not an integer ratio. This means that there is a part that cannot only be handled with integers. Moreover, although 3D scenes modeled and rendered with well-known commercially available CG applications should be viewed stereoscopically, these CG applications usually do not support hexagonal pixel arrangements. This paper describes a method of synthesis that can be applied to these cases.

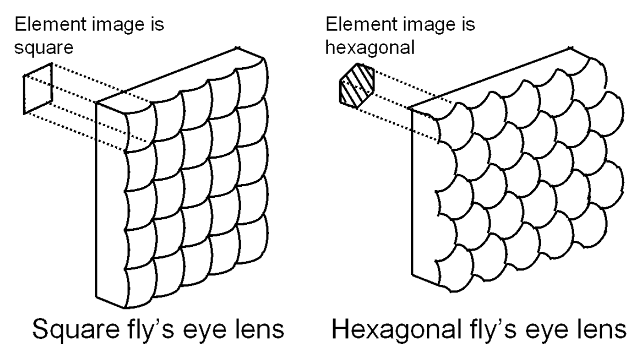

***Figure 1**. Two kinds of fly's eye lens sheets*

Principle Underlying Proposed System

The flow for the new method is outlined in Figure 2. Half the proposed method is the same as the existing method in which hundreds of still images are taken with a real or virtual camera from different angles. The other half of the method is only for cases using the hexagonal fly's eye lens. The displacement from the center of the nearest hexagonal lens is calculated for all pixels in the IP image. Since this displacement corresponds to the direction of a ray emitted from the pixel, the camera position nearest to the ray is calculated from hundreds of camera positions. A pixel position that corresponds to the hexagonal lens is calculated from the image taken from the camera position, and the pixel value is set to the pixel of the IP image. Finally, the IP image is scaled to the final IP image so that the size matches the hexagonal fly's eye lens sheet.

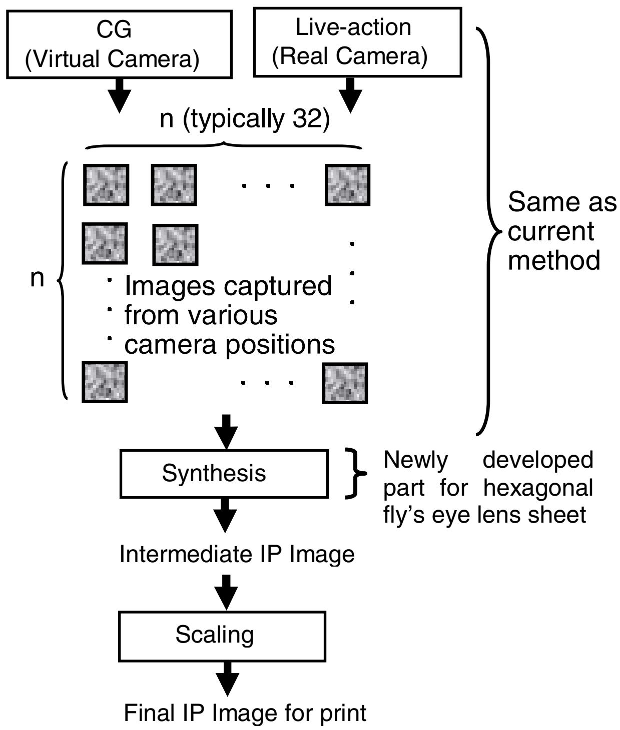

***Figure 2**. Flow for proposed method*

Figure 2 shows the flow for the method we propose. Half the method is basically the same as the current method that has been discussed in past papers [3]–[6]. As we can see from Figure 3, the camera not only moves parallel to but also rotates towards the look-at point, which corresponds to the position of the center of the fly's eye lens sheet. Therefore, $n \times n = n^2$ images are captured by the camera from different positions. Here, both live action and CG can be used to capture the images. That is, the camera is real for live action, and it is virtual for CG. If n has a large value, the change in the image caused by the movement of viewpoint becomes smooth, but the volume of data increases. A typical value for n is 32.

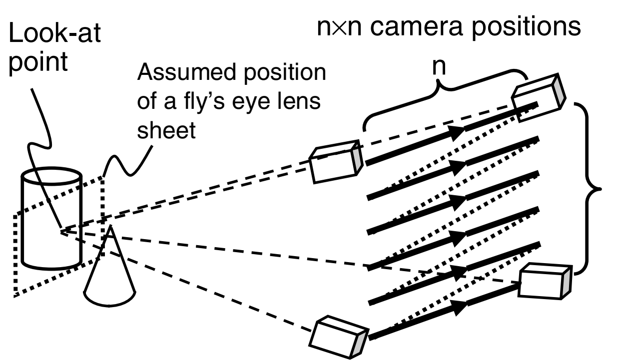

***Figure 3**. Change in camera position*

An intermediate IP image, whose resolution is different from that of the final IP image for printing, is synthesized as follows. As we can see from Figure 4, it is necessary for the period of the lens, in other words, the distance between two adjacent lenses, to differ depending on the direction. When the length of a side of a hexagon is assumed to be one, the vertical lens pitch is 1.5 and the horizontal lens pitch is $\sqrt{3}$. Because $\sqrt{3}$ is an irrational number, the ratio between the horizontal lens pitch and the vertical lens pitch is not an integer ratio. This means that it is impossible to make the ratio of the pixel pitch to either the horizontal lens pitch or the vertical lens pitch an integer ratio no matter how the pixel pitch is chosen if the pixels in the IP image are square.

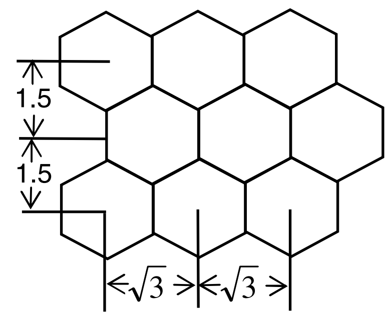

***Figure 4**. Horizontal and vertical lens pitch*

Even in this case however, the displacement from the center of the nearest hexagonal lens is calculated for all pixels in the IP image. Even though the result does not become an integer but a real number, this does not matter.

Considerable attention has recently been paid to the fractional view method proposed by Ishii [7][8]. It is a new 3D-display method using a lenticular lens sheet in which the ratio between the lens pitch and the pixel pitch of the display device are selected to be a non-integer value in the design. The method has many advantages. For example, the change in the observed images between views becomes smoother when the observer's eyes move. The ratio between the pixel pitch and the lens pitch inevitably becomes a non-integer ratio at least horizontally or vertically with our method. It can therefore be considered to be a kind of fractional view method. We chose the number of pixels per side of a hexagon to be an integer. A typical value for the integer is 20 when the value of n is 32.

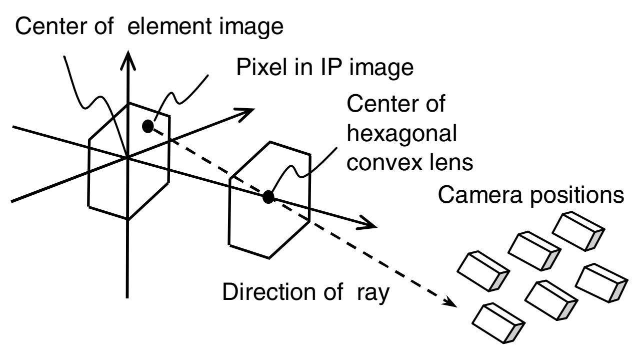

***Figure 5**. Synthesis method*

As we can see from Figure 5, the path of light leaving the pixel, for each pixel in the intermediate IP image, and passing through the nearest hexagonal lens is traced, and the nearest camera position from the ray is calculated from n × n=n^2 camera positions. Note that the position of the center of the element image is usually expressed by a real number in this case not an integer.

Which pixel of the image taken from the camera position corresponding to the ray is next calculated. We can see from Figure 3 that the camera does not always take a picture from immediately in front of the assumed position of the fly's eye lens sheet. Therefore, it is necessary to transform 3D coordinates to accurately obtain the pixel positions in the image. The camera can be considered to be a parallel projection device when its viewing angle is not wide. Because the depth axis, W, of the camera coordinate system, UVW, becomes unnecessary in that case, the camera coordinate system can be translated so that the origin of the camera coordinate system UVW and that of the global coordinate system XYZ meet as shown in Figure 6.

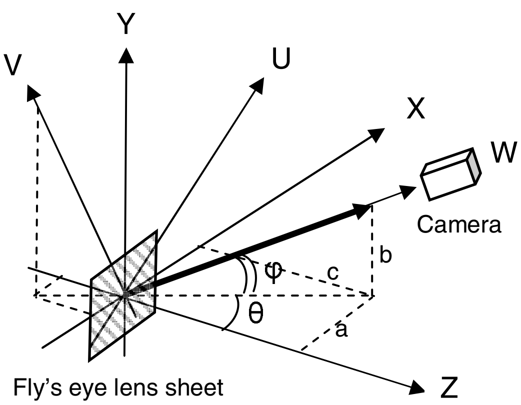

***Figure** 6. 3D coordinate transformation*

From Figure 6,

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\varphi\sin\theta & \cos\varphi\sin\theta \\ 0 & \cos\varphi & \sin\varphi \\ -\sin\theta & -\sin\varphi\cos\theta & \cos\varphi\cos\theta \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} \quad (1)$$

Because the transformation matrix is an orthogonal matrix, its inverse matrix is its transposed matrix. Therefore,

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ -\sin\varphi\sin\theta & \cos\varphi & -\sin\varphi\cos\theta \\ \cos\varphi\sin\theta & \sin\varphi & \cos\varphi\cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (2)$$

Assume the camera position in the XYZ coordinate system to be (a, b, c). Then, from Figure 6,

$$\left.\begin{aligned} \sin\theta &= \frac{a}{\sqrt{a^2+c^2}} \qquad \cos\theta = \frac{c}{\sqrt{a^2+c^2}} \\ \sin\varphi &= \frac{b}{\sqrt{a^2+b^2+c^2}} \qquad \cos\varphi = \frac{\sqrt{a^2+c^2}}{\sqrt{a^2+b^2+c^2}} \end{aligned}\right\} \quad (3)$$

Therefore,

$$u = \frac{c}{\sqrt{a^2+c^2}}x \quad (4)$$

and

$$v = \frac{-ab}{\sqrt{a^2+c^2}\sqrt{a^2+b^2+c^2}}x + \frac{\sqrt{a^2+c^2}}{\sqrt{a^2+b^2+c^2}}y \quad (5)$$

By using Equations (4) (5), the coordinates (u, v) in the camera coordinate system, UV, can be calculated from the coordinates of the lens that exists at (x, y) in the XY coordinate system. Therefore, pixel data whose coordinates are (u, v) can be read from the image taken from the camera position, and set to an IP image pixel whose coordinates are (x, y). The same procedure is repeated until all the pixels in the IP image are processed.

Finally, the IP image is scaled to the final IP image so that the size matches the hexagonal fly's eye lens sheet.

Experiments

The number of pixels per element image was 32 × 32 in these experiments, and there were 180 × 180 element images. These images were rendered by using Shade™, which is a product of e frontier. It is a well-known CG application.

The fly's eye lens used in the experiment was Koyo's No. 360, whose dimensions are in Figure 7.

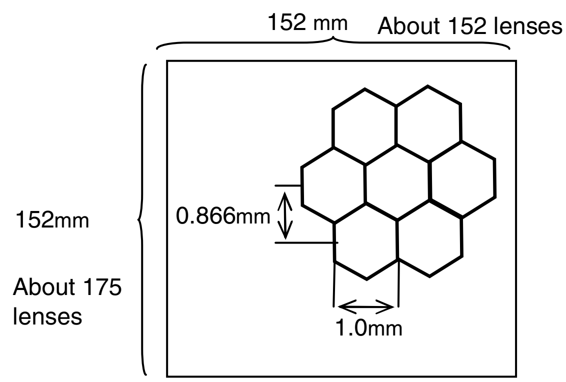

***Figure** 7. Dimensions of fly's eye lens sheet*

An inkjet printer for consumer use (EPSON PM-G850) was used to print the IP image. Since the physical resolution of the printer was 5760 × 1440 dpi, we first set the resolution to 880 dpi because this was the resolution of the final IP image (20×1.5×25.4/0.866=880). We then scaled it to 1440 dpi without changing the physical size of the image, and printed the final IP image at this resolution.

The experiments demonstrated that excellent binocular vision could be obtained using the method shown in Figure 8, as we had predicted theoretically. Not only horizontal but also vertical parallax was observed.

Conclusion

A new method of image synthesis for integral photography has been proposed. It can be applied to cases where the shapes of all convex lenses in the fly's eye lens sheet are hexagonal not square. As the ratio of the horizontal lens pitch to the vertical lens pitch is irrational in these cases, the ratio between the pixel pitch and the lens pitch cannot be an integer ratio at least horizontally or vertically when the pixels are square. This complicates the situation. Even in these cases, however, an IP image can be synthesized with the new method. We confirmed that excellent binocular vision could be obtained using the method through experiments. A ready-made hexagonal fly's eye lens sheet and a ready-made printer can be used because the difference in parameters, e.g., the lens pitch and resolution of the printer, are compensated for by a scaling process.

***Figure** 8. Photograph of real 3D printout covered by hexagonal fly's eye lens sheet*

Acknowledgement

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Author Biography

Kazuhisa Yanaka received his B.E., M.E., and D.E. from the University of Tokyo in 1977, 1979, and 1982. He joined the Electrical Communication Laboratories of NTT in 1982 and he was engaged in the research and development of videotext terminals, teleconferencing systems, and image coding algorithms. He joined the Kanagawa Institute of Technology, Japan, in 1997 where he is currently a professor.