Synthesis of Integral Photography Images Using Shade™

Kazuhisa Yanaka, Hideo Kasuga, Yasushi Hoshino, Koichiro Kuroda**, Takeshi Hakii**, and Hirokazu Sato***
Kanagawa Institute of Technology, Atsugi, Kanagawa, Japan
**Nippon Institute of Technology, Miyashiro, Saitama, Japan*
***Konica Minolta Photo Imaging,Inc., Hino, Tokyo, Japan*

Abstract

This paper proposes a new technique to produce high quality integral photography (IP) images. IP is an ideal 3D image display system in which viewers can see realistic 3D images from arbitrary directions without wearing special glasses. In addition, IP is excellent with printing technologies since both pinhole arrays and IP images can be printed on transparent sheets by high resolution printers. Up to now IP images were produced by using CG or photography, but the quality of the CG images was not always satisfactory, since only simple objects such as cones or spheres were used. Shade™ is a commercial three dimensional CG application with abundant powers of expression, and is very popular among professional CG artists especially in Japan, since it is suitable for expressing complex shapes such as human bodies with delicacy. By controlling the camera position of Shade by a script language, and synthesizing an IP image from resultant still images according to our algorithm, the authors achieved the 3D display of realistic scenes created with Shade.

Introduction

3D display is the technique which presents the viewer with an image of a 3D object such that it appears to have real depth. Integral photography[1] (IP) is an ideal 3D display system since viewers can observe realistic 3D figures appropriate for the viewpoint even if the viewpoint moves horizontally or vertically. No special glasses are required. Integral photography was first presented by G.Lippmann in 1908, in which fly-eye lens was used. In 1911 A. Sokolov showed that integral images could be produced using a pinhole array.

In recent years a system[2] was proposed in which both an IP image and a pinhole array are produced by using printing technology, with a backdrop of the advent of high resolution and high quality inkjet printers which can print images on transparent OHP sheets. Here an IP image is an image in which all the information necessary for 3D display is integrated. Besides, through our experiments it has been found that the adoption of silver halide printers contributes greatly to the improvement of the picture quality. Meanwhile, data compression algorithms for IP images are being studied.[3]

Techniques for producing an IP image fall into two basic categories. One is capturing of real objects with a camera,[4] and the other is CG (Computer Graphics). In the latter case however, it was not easy to create complex objects such as human bodies, cars, animals and plants.

Shade™ is one of the most popular 3D CG modeling and rendering applications in Japan, and it is a product of e frontier, Inc. Since it supports free-form surfaces based on Bezier curve, graceful objects can be created. In this research, a scene file created with Shade is rendered with Shade from many viewpoints under the control of a script, and many still images are obtained. Here, the script was written in Microsoft JScript. An IP image is then synthesized from the still images by our original software, which was written in C language. This research enables us to view 3D objects modeled by Shade directly.

Principle of Integral Photography

As shown in Figure 1, a pinhole array has been printed on the upper transparent sheet in advance. An IP image has been printed on the lower transparent sheet. A transparent board is inserted between the two transparent sheets in order to keep the distance between the two sheets constant. The lower transparent sheet is illuminated by a back light. Each viewer sees the light which passes through the pinhole array. In this case, the viewer's right eye cannot distinguish which of Q and S is the true light source. In the same way, the viewer's left eye cannot distinguish which of R and S is the true light source. Therefore the viewer feels as if the light were emitted from Q according to the binocular parallax, and perceives the existence of an object at Q.

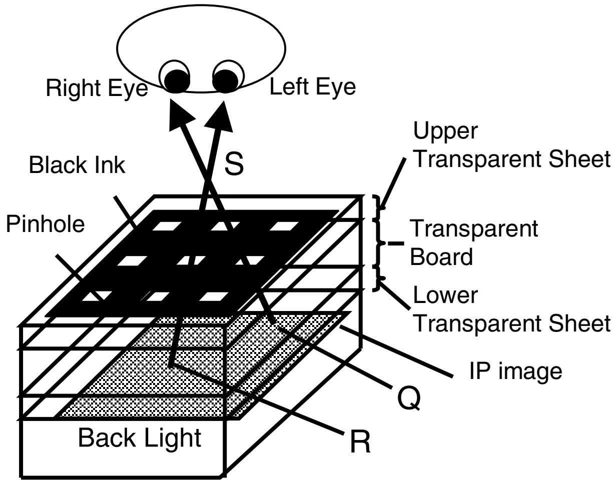

Figure 1. Principle of integral photography using printing technology

Synthesis of IP Images

One of the most significant issues of integral photography is the way to create the IP images. Figure 2 shows the process flow of the proposed system. Shade 6 Advance was used for both modeling and rendering. However a script, which is required for camera control and written in Microsoft JScript, was developed by the authors. In the experiment described later, n=32. The program for synthesizing IP images, is also written in C language by the authors.

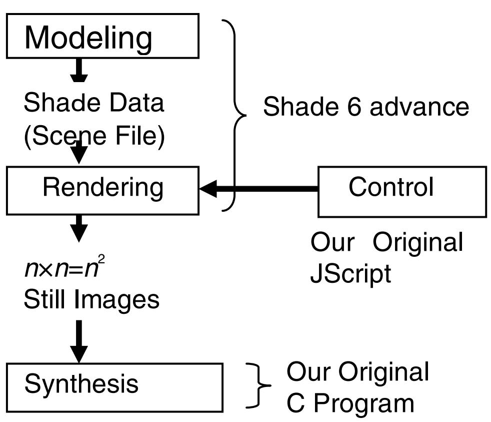

Figure 2. Process flowchart

First, a scene file is created by using the modeling function of Shade. At that time a viewpoint and a look-at point are set in the file. Subsequently, $n \times n$ still images are captured by changing the camera position and orientation as shown in Figure 3. Here the camera is always on the plane witch is orthogonal to the viewing vector and the center of which is the viewpoint **p**. Regardless of the camera position on the plane, the camera is controlled so that it always turns toward the look-at point. The camera is a parallel projection camera.

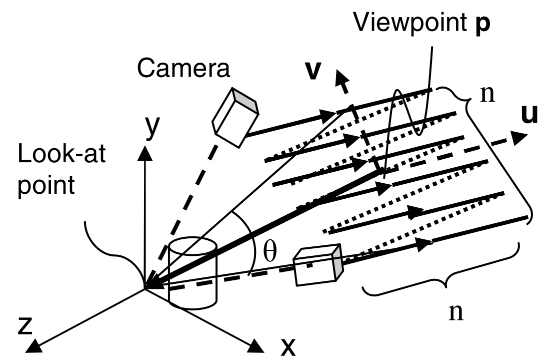

Figure 3. Camera positions

Shade has the right hand coordinate system. The xyz coordinate system should be a translated one of the world coordinate system of Shade. The origin of the xyz coordinate system should be the look-at point embedded in the shape data. In the xyz coordinate system, the coordinates of the viewpoint are given by $\mathbf{p} = (x_v, y_v, z_v)$. **u** and **v** are the two unit vectors, orthogonal to the vector which is headed from the origin to the viewpoint **p**. Then,

$$\mathbf{u} = \left(\frac{z_v}{\sqrt{x_v^2 + z_v^2}}, 0, \frac{-x_v}{\sqrt{x_v^2 + z_v^2}} \right) \tag{1}$$

$$\mathbf{v} = \left(-\frac{x_v y_v}{w}, \frac{x_v^2 + z_v^2}{w}, -\frac{y_v z_v}{w} \right) \tag{2}$$

where

$$w = \sqrt{(x_v y_v)^2 + (x_v^2 + z_v^2)^2 + (y_v z_v)^2} \tag{3}$$

The coordinates of the camera position of i-th from the top and the j-th from the left ($0 \le i, j \le n-1$) is

$$\mathbf{p} + (\frac{2j}{n-1} - 1) l \tan\frac{\theta}{2} \mathbf{u} + (\frac{2i}{n-1} - 1) l \tan\frac{\theta}{2} \mathbf{v} \tag{4}$$

where l is the length of vector **p**, and θ is the vertical or horizontal viewing angle. Here the field of view is assumed to be square.

Next, an IP image is synthesized from n × n still images captured with the camera. As shown in Figure 4, it is assumed that a pinhole array is on the xy plane and an IP image is slightly behind the pinhole array. The distance between them is d. The size of a unit image is equal to the number of camera positions, namely n × n. The coordinates of each pixel within a unit image are (*i*,*j*) $(n \leq i, j \leq n-1)$. Then the vector (a,b,c) which indicates the direction of the light is as follows.

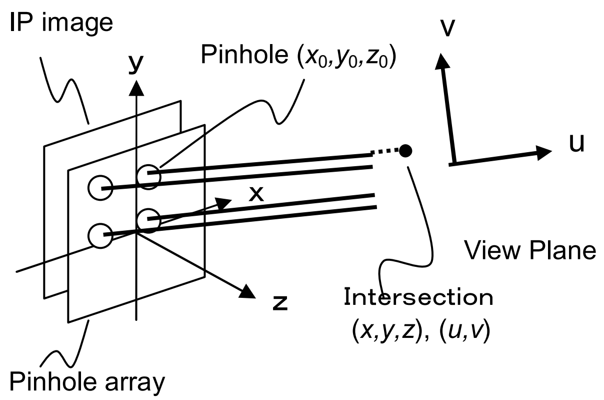

Figure 4. 3D Viewing coordinates

$$(a,b,c) = (\frac{n-1}{2} - j, \frac{n-1}{2} - i, d) \tag{5}$$

If the position of the pixel within each unit image is the same, the beams of light which are emitted from different pixels and pass through different pinholes are parallel each other. Therefore the beams are captured by a camera simultaneously. Consequently, each pixel value of the IP image can be determined by tracking the light ray back to the captured image as shown in Figure 4.

The coordinates of a pinhole is (x_0, y_0, z_0). The equation of a beam of light which is emitted from the pinhole is

$$\begin{aligned} x &= x_0 + at \\ y &= y_0 + bt \\ z &= z_0 + ct \end{aligned} \tag{6}$$

where t is a parameter. It is assumed that an image is captured by a parallel projection camera from the same direction of the beam, and the coordinate system within the view plane is uv. Then the intersection of the beam and the view plane is (u, v) in uv coordinate system. It is obvious from Figure 4 that the coordinates (u, v) remain unchanged even if the view plane is translated along the beam of light so that it passes through the origin. Therefore the view plane is translated so as to simplify the calculation. After the translation, the equation of the view plane is as follows.

$$ax + by + cz = 0 \tag{7}$$

The value of t at the intersection of the beam of light and the view plane is obtained from equations (6) and (7).

$$t = -\frac{ax_0 + by_0 + cz_0}{a^2 + b^2 + c^2} \tag{8}$$

Substituting equation (8) into equation (6) yields the coordinates of the intersection in xyz coordinate system. Moreover, The coordinates (x, y, z) of the world coordinate system can be transformed into the coordinates (u, v) of view plane coordinate system as follows.

$$u = \frac{cx - az}{\sqrt{a^2 + c^2}} \tag{9}$$

$$v = \sqrt{\frac{a^2 + b^2 + c^2}{a^2 + c^2}}\, y \tag{10}$$

The pixel value of the still image corresponding to the coordinates (u, v) is set to the pixel of the IP image, which is slightly behind the pinhole.

Experiments

The authors chose test data for experiments from "Shade Practical 3D Data Collection Complete Edition 1," which is also a product of e frontier, Inc. Figure 5 shows an example of stereoscopically displayed image. The original data is paper03_shd, which is included in DISC-3. The photograph shown in Figure 5 is taken with a digital camera. In this experiments, following parameters are used.

The number of pixels per pinhole is 32 × 32.
The number of pinhole is 180 × 180.
Accordingly the number of pixels of an IP image is 5760 × 5760.

Two printers are used in the experiments.
(i) An inkjet printer for consumer use (720dpi)
(ii) A silver halide photography printer for institutional use (400dpi)

In both cases, good stereoscopic vision was possible.

Figure 5. An example of displayed 3D image

Conclusion

A technique has been proposed in which IP images are produced from Shade scene files. Through experiments it has been confirmed that 3D display is possible by the proposed system. The proposed system is also applicable to the cases in which fly-eye lens is used, since a convex lens is a functional equivalent of a pinhole. This research is expected to contribute to the spread of integral photography.

References

1. Graham Saxby, "The Science of Imaging: An Introduction," Institute of Physics Publishing, Bristol, UK, 2002.
2. Susumu Sasaki, Hideo Kasuga, Kazuhisa Yanaka and Yasushi Hoshino, "3D Display System Using High Resolution Transparent Printer Output," Proc. IS&T's NIP18, pp.807-810, San Diego, Sept-Oct.2002..
3. Kazuhisa Yanaka, Hideo Kasuga and Yasushi Hoshino, "Image Compression for Integral Photography," Proc. IS&T's NIP19, pp. 850- 853, New Orleans, Sept-Oct.2003.
4. Hideo Kasuga, Kazuhisa Yanaka, Susumu Sasaki and Yasushi Hoshino, "3D Image Input System for High Resolution Integral Photography," Proc. IS&T's NIP19, pp. 846- 849, New Orleans, Sept-Oct.2003.

Biographies

Kazuhisa Yanaka is a professor of Kanagawa Institute of Technology, Japan. He gained BE, ME and Dr.Eng. degrees from the University of Tokyo, in 1977, 1979, and 1982 respectively. He joined Electrical Communication Laboratories of NTT in 1982 and developed videotex terminals, teleconferencing systems, and image coding algorithms. He moved to Kanagawa Institute of Technology in 1997.

Hideo Kasuga is a research associate of Kanagawa Institute of Technology, Japan. He gained BE, ME and Dr.Eng. degrees from Shinshu University in 1995, 1997, and 2000 respectively. He worked at the university as a research associate for months, and he moved to Kanagawa Institute of Technology in 2000. His main research field is image processing.

Yasushi Hoshino is a professor of Nippon Institute of Technology, Japan. He gained BE, ME and Dr.Eng. degrees from the University of Tokyo, in 1970, 1972, and 1984 respectively. After he gained ME degree, he joined Electrical Communication Laboratories of NTT and developed LED printers, laser printers, and ion flow printers. He moved to Nippon Institute of Technology in 1994. He published more than 20 papers, including several papers in IS&T's journal. He attended almost all NIP conferences.

Koichiro Kuroda is Assistant Manager of Konica Minolta Photo Imaging,Inc. He received his M.S. degree in organic chemistry from the Saitama University in 1993. He joined Konica Corporation the same year, and, since then, has been engaged in the research and development of silver halide photographic materials.

Takeshi Hakii is Chief of Konica Minolta Photo Imaging,Inc. He received his bachelor's degree in chemical engineering from the Waseda University in 1995. He joined Konica Corporation the same year, and, since then, has been engaged in the research and development of silver halide photographic materials.

Hirokazu Sato is Manager of Konica Minolta Photo Imaging,Inc. He received his M.S. degree of engineering in chemistry from Tokyo Institute of Technology in 1984. He then joined Konica Corporation, where he has since been engaged in the research and development of color photographic materials.