回転板式３次元テレビジョン

Spinning-disc 3D Television

- Multiple parallax image camera and display using Nipkow disc -

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Abstract: In this study, we have incorporated a novel LED-projection technology into the simple structure of a spinning-disc television. A spinning-disc television is a well-known vintage system used for transmitting television images. In order to display 3D images, we have replaced the conventionally used light bulbs in this system with an LED array. In order to capture the parallax images, we replaced the light-sensitive tube with a photo-diode array. With the aid of this technology, users can capture multiangle images of the target and view different images from different viewing angles.

Keywords: Nipkow-disc, 3D image, Parallax images, Autostereoscopic display.

1. Introduction

The aim of our study is to develop an image display technology that eliminates the distance between two spaces so that users can perceive an object in 3D. At present, several stereoscopic systems such as head-mounted displays (HMDs) [Ivan65] and immersive multi-screen display units such as CAVE [Carolina93]) are available. These systems require the observer to wear special glasses for stereopsis. However, it is more convenient to view a display without wearing special glasses. In order to overcome this problem, parallax barriers and lenticular lenses have been used in a number of systems. Keeping this in mind, we previously developed two systems—TWISTER [Susumu96] and Seelinder [Tomohiro05]—that realize an autostereoscopic display without requiring special equipment to be worn. The TWISTER system works as a cylindrical display and has multiple rotating LED (light emitting diode) boards. Each LED board consists of a linearly-arranged LED array and has a slit-shaped parallax barrier. The observer stands in the cylindrical drum and is able to view the entire autostereoscopic image through a slit in the appropriate LED array. The Seelinder system also works as a cylindrical display. The differences between these systems lie in the direction of the rays and the motion of the parallax barrier. In the Seelinder system, the observer stands outside the cylindrical drum and views the image through the slit in the appropriate LED array. These systems provide level parallax images only. Because the parallax barrier shaped thin and long slit.

In this study, we extend the abovementioned prototypes in order to be able to construct a more natural 3D "presence" of objects. Next, we examine the possibility of realizing a display with a pinhole parallax barrier shaped small hole. This type of parallax barrier can display both horizontal parallax and vertical parallax at the same time. The concept of this system is same as that of integral photography; however, there is a trade-off between the resolution and the number of parallaxes. In order to resolve this problem, as the pinholes rotate, the LEDs flash several times. As a result, the system displays a compact image. We have utilized this concept in our study and have described the structure and use of a spinning-disc television system that is capable of producing multiple parallax images.

Figure 1: Photograph of the Televisor, which is currently owned by the Museum of Broadcasting, Tokyo, Japan

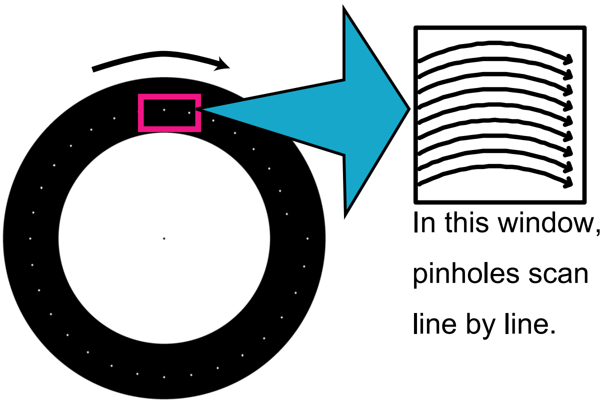

Figure 2: Illustration of the Nipkow disc. The pinholes are placed in a spiral.

2. Spinning-disc 3D television

The first spinning-disc television system, shown in Figure 1, was publicly demonstrated by J. L. Baird in 1926 [Ronald33]. In the initial days, a number of these television units were sold. This television system had a spinning disc, a light bulb located behind the disc, and a signal-receiving circuit. The camera system also had a spinning disc and a photo-detecting device located behind the disc. The disc in the television spun in synchronization with the disc in the camera system. Moreover, the bulb flashed in synchronization with the photo-detector in the camera system. The spinning disc in this system is also known as the Nipkow disc and the structure is shown in Figure 2. It is image scanning device to reconstruct the television image. From this system, we found that the spinning disc can be used to display multiple parallax images. We therefore extended its application to televisions used to display 3D images. Next, we describe the concept, structure of the camera unit, display unit, and the design of the parallax image for the system developed in our study.

2.1. Concept of proposed system

The basic concept of the system developed in this study is based on that of the spinning-disc television, which is shown in Figure 3. We improved this system so that it captures light rays from a specific direction and projects them in a specific direction.

Our system can display multiple images based on the viewer's line of sight. It is capable of displaying both horizontal and vertical parallaxes.

The concept of a 3D parallax display that utilizes a spinning disc was suggested by Yendo at el[Tomohiro06]. He developed an experimental display using the Nipkow disk and emphasized the importance of time multiplexing in such systems. We also focus on this concept and apply it to the 3D television system developed in this study.

Figure 3 shows the principle of our system. The system consists of a camera unit and display unit. Both units are connected by a wire. Multi-parallax images are captured by the camera unit and then transmitted to the display unit that displays the multi-parallax images at the same time.

2.2. Structure of camera unit

The camera unit used in our system comprises the following three components:

(1) The spinning disc, also known as the Nipkow disc, controls the rays of light that pass through the holes in the disc. The holes are arranged in a spiral formation. The light that passes through the holes as the disk rotates produces a raster scanning pattern with a rectangular area. As a result, the disc can either convert the temporal modulated light

(2) A convex lens is located behind the Nipkow disc and it captures the rays incident on it. The focal length is equivalent to the distance between the lens and the photodiode (PD) array. The convex lens focuses a ray

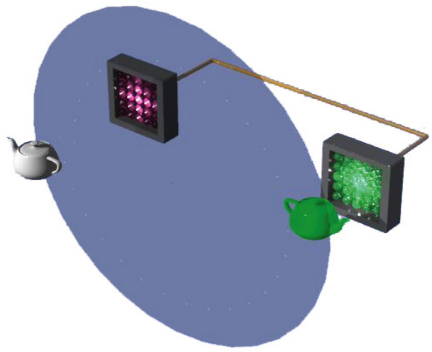

Figure 3: Schematic representation of spinning-disc 3D television (this system has both a camera and a display unit).

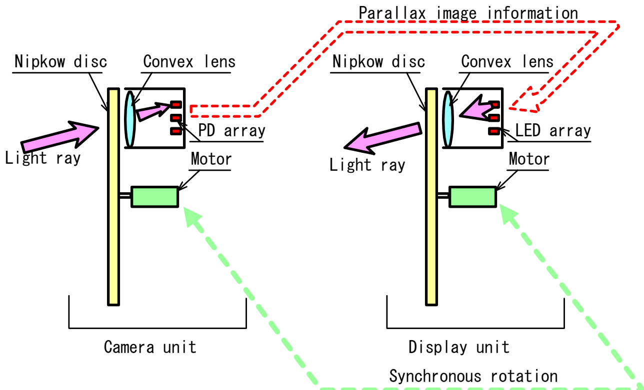

Figure 4: The concept illustration of Spinning-disc 3D television

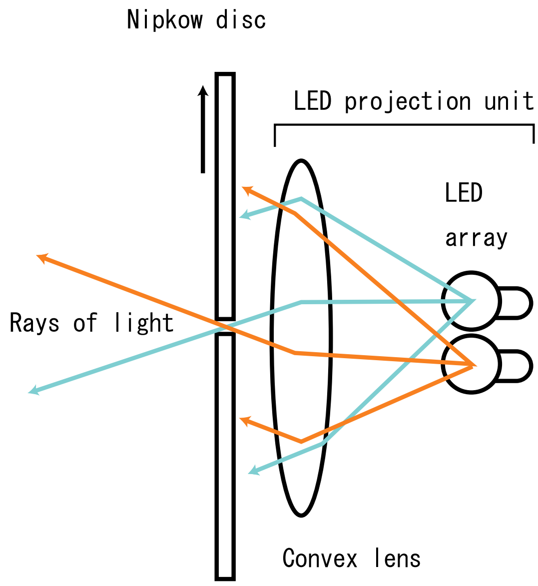

Figure 5: Light path from light source to the front section

Each cell of the array captures light from a specific direction. The output signal of the cell is a temporal signal that is scanned by the Nipkow disc. The outputs of the PD array convey information about the multi-parallax images. Conventionally, the photodiode array employs only a single light detector, which is placed behind the disc. However, in our system a separate light detector array has been allocated for each viewing direction.

With the aid of these components, the system can capture multiple parallax images.

2.3. Structure of display unit

The display unit has a structure that is almost similar to that of the camera unit except that the path of each ray of light in the display unit is the reverse of that in the camera unit. It comprises three components:

Figure 8: Photograph of Spinning-disc 3D television.

(1) A Nipkow disc, which spins in synchronization with the disc in the camera unit. As a result, the pinholes on both the discs are aligned at the same angle and position.

(2) A convex lens, which converts the ray of light from a point light source into a straight ray.

(3) An LED array that can display multiple images simultaneously. The conventional Nipkow disc employs only a single bulb and is capable of displaying only a single image. However, in our new system, each LED element displays different images and an observer can view different LED elements through the hole in the disc. This principle is illustrated in Figure 5.

2.4. Design of the parallax images

In order to capture or display parallax images, we have to design the system based on the number of images and the number of LED devices on the array. The important parameters to be considered are as follows:

(1) Size of the screen.
(2) Resolution of the screen.
(3) Viewing angle of the screen.

The main parameter that affects the size of the image is the distance between the pinholes on the Nipkow disc.. The resolution of the image is limited by the number of pinholes on the Nipkow disc. The size of the Nipkow disc can be solved by the product of the screen width and the number of scanning line of image . However, the size of the Nipkow disc is limited by the stress of the torque and the size of the display unit.

The main parameter that affects the viewing angle is the distance between the LED array and lens. This relationship is shown in Figure 6. The width of the LED array is denoted by . The width of each LED is . The distance between the Nipkow disc and the LED is denoted by . The observer stands on the left hand side in this figure and can view the image depending on the position of his/her head.

The viewing angle (θ_w) can be calculated by the following equation.

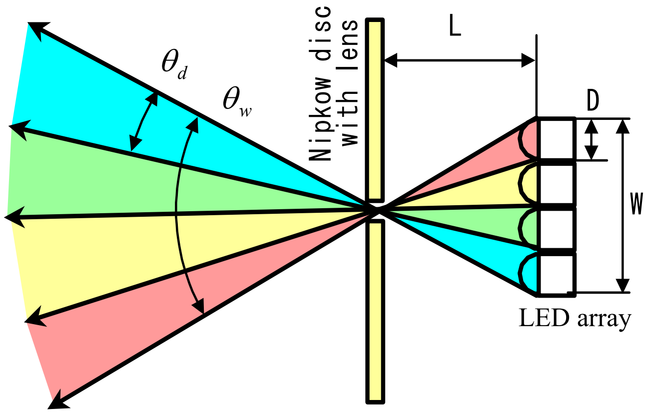

Figure 6: Explanatory drawing of the viewing area

$$\frac{\theta_w}{2} = \arctan\left(\frac{W}{2L}\right)$$

The viewing angle of the individual image can be roughly calculated by the following equation.

$$\theta_d = \arctan\left(\frac{D}{2L}\right)$$

The number of images to be displayed is calculated by taking into account the various positions that can be assumed by a human head.

2.5. Design of the control unit

This type of television system does not require the use of a complex control unit. We use a simple technique to synchronize the two discs and connect a wire from a cell in the PD array to one in the LED array. The display unit is capable of showing not only the captured image but also 3D computer graphics (CG) images. In order to display CG images, a video signal generator is required for the display of the parallax images. The process involved in the display of these images will be described later. The generator consists of the following three components

(1) A clock generator, which is synchronized with the

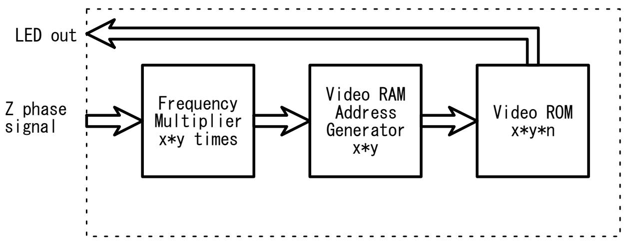

Figure 7: The function of the parallax image generator

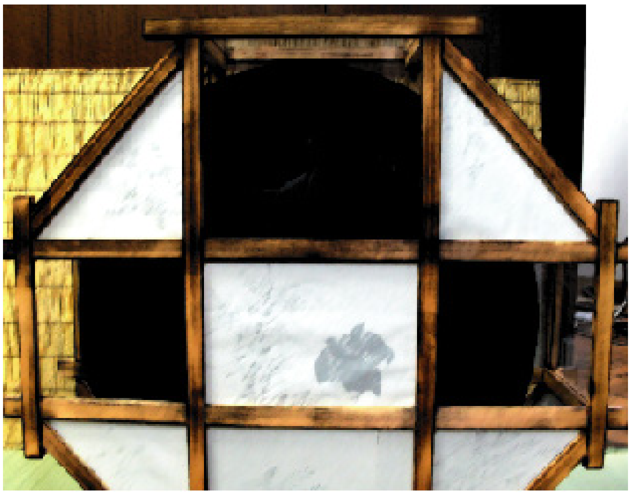

Figure 8: Spinning-disc 3D Television

Nipkow disc and which acts as the time-base generator.

(2) An address generator, which is used to map the position of the pixel on the screen to an address in the memory.

(3) A memory that is used to store the parallax images that comprise the video signal.

Figure 7 shows the working of the parallax image generator. The values x and y indicate the size of the screen in pixels.

3. Implementation

We have developed a prototype television system (see Figure 8).This prototype system has a 700-mm-diameter Nipkow disc with 64 holes. This size is selected for the baggage by the air. And it has one camera unit and two display unit on the same Nipkow disc. Figure 9 show the Nipkow disc with two display unit and there is one more camera unit behind of the disc. Because of the size limitation, we decided to develop the camera and display on same disc. It is clearly expandable to long distance television.

As for the display unit, it has sixty-four full-color LEDs placed behind the disc, and the observer can view eight by eight (sixty-four) different images from his/her viewing position. The viewing angle is 60 degree and observer can see autostereoscopic images from 300 mm distance at any position. The camera unit is designed same method but the limitation of the component size, the number of parallax image is 32.

The screen resolution is 64 × 64 pixels and the screen size is 32 mm × 32 mm (see Figure 10). This value is selected by the balance of the screen size and screen resolution. The frame rate is about 12 frames per second (fps) because of the power limitation of the motor.

Therefore, 32 different images can be captured and 64 different images can be displayed. We describe several components in detail.

3.1. Nipkow disc

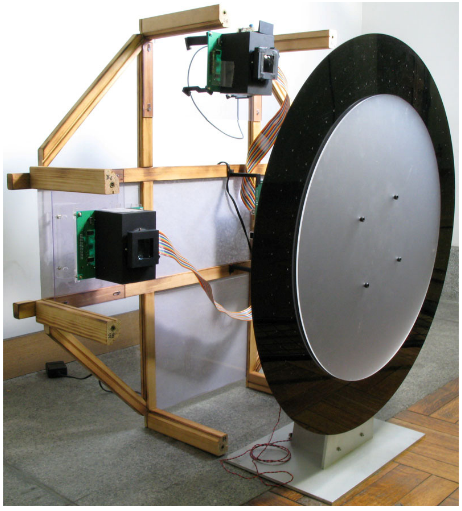

Figure 9: Photograph of internal components.

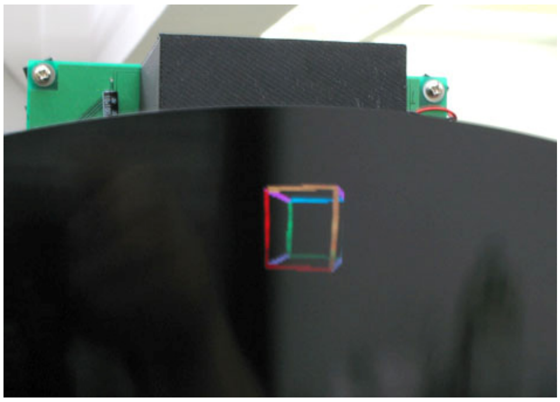

Figure 10: Photograph of display image.

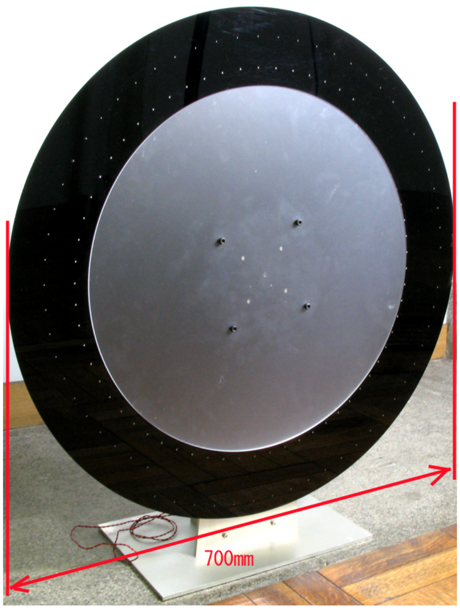

Figure 11: Photograph of Nipkow disc

Figure 11 show the Nipkow disc in practical use. This disc has 64 pinholes. The pinhole has a cone-shaped hollow and a diameter of 0.8 mm. The disc consists of a polycarbonate plate with a thickness of 2 mm. It is extremely important to shape and position the holes on the disc accurately. The polycarbonate plate used is extremely thin and hence must be supported by a translucent guide plate.

A motor (10 W DC motor from Maxon Motor Corp.) is installed at the back of the Nipkow disc and has a speed of 12 rotations per second.

3.2. Display unit

The display unit consists of 64 full-color LEDs (over 2 cd brightness, OSTA71A1D), which were mounted on a printed circuit board with a pitch of 8.89 mm (see Figure 12). Each LED is driven by a serial line from the control board. Since the projecting rays from each LED are not of equal intensity, we use a diffuser, which consists of Japanese paper and black plastic, to decrease the stray light from the next LED. The lens on the LED consists of a cemented doublet with a diameter of 53.5 mm and a focal length of 75 mm. The black covering for the display unit was prepared by using a 3D printer.

3.3. Camera unit

The camera unit consists of an array of 32 PDs (BPW34 from Vishay Corp.) (see Figure 13). This unit is designed for enhancing up to the 64 PDs in the future. The unit also has a current to voltage converter (OPA2335E from TI Corp.) with an amplitude of 1 [V/mA]. In addition to the amplifier, a comparator with a sensitivity of approximately 0.05 [V/mA] is also present. The bandwidth of this system is approximately 1 [MHz]. The low noise amplifier used in this unit provides the most important challenge. The output of the comparator is connected to the control board with a parallel line. The lens on the PD is the same as that on the display unit.

If the sensitivity is too low to capture a clear image, a shadowgraph of the object is obtained.

3.4. Control unit

control board detects a Z phase signal (this is a pulse signal that indicates the instant at which the disc starts rotating) and it generates a clock depend on the resolution of the image. In our system, a board generate a clock which is multiplied 4096 times for the 64 × 64 pixels image. In this configuration, the frequency of the dot clock is approximately 50 [kHz]. In a single pixel period, the pixel data of 64 different parallax images is transmitted.

The second mode is used to render a captured image. In this mode, the camera unit is connected to the control board using a parallel line, while the display unit is connected using a series line. Each board used in this unit generates some error. Hence, the control board adjusts the signal

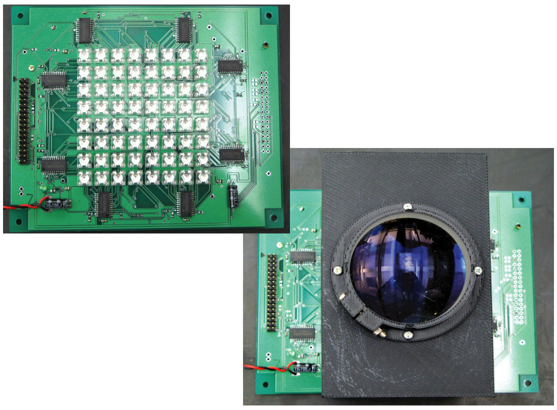

Figure 12: Photograph of display board.

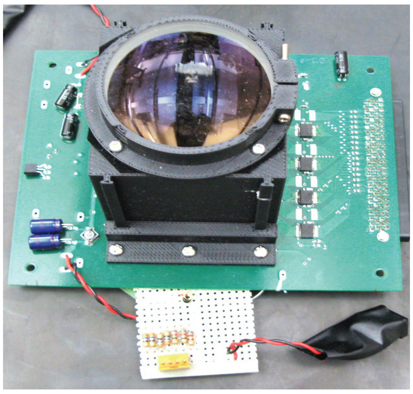

Figure 13:Photograph of Camera board

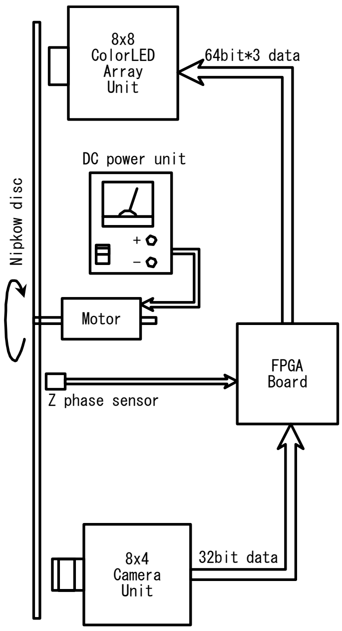

Figure 14: The block wiring diagram of proposal system

timing and converts the parallel data into serial format. The final system is shown in Figure 14. Figure 15 shows the typical images on the display at the same time.

4. Discussion

The television system developed in this study was exhibited at SIGGRAPH 2007, San Diego and at Asiagraph 2007, Tokyo. Our system was viewed by a large number of people. The feedback given by the observers was also taken into consideration. Many observers were able to clearly view the 3D CG image clearly (Figure 16 shows the one of the sample image)by adjusting the positions of their heads. Given below are some of the limitations of our system as pointed out by the observers and the possible explanations for these limitations.

(1)The size of the screen is quite small: This is true.

(2)The clarity of perception decreases with distance: This may be due to the fact that the positions of the heads of the observers varied from the ideal setting, resulting in reduced clarity of the image.

(3) Flickering of the screen: This is due to the fact that the number of frames per second (12 frames per second) is too slow to show the natural image. The slow frame rate is because the power of the motor is too low and a strong driver is required.

(5)The image from the camera unit is unrecognizable: This problem occurs due to insufficient image sensitivity.

Thus, our television system has been implemented successfully and allows users to observe 3D images without the use of special equipment.. However, the camera unit still has some drawbacks..

5. Conclusions

In this study, we examined the possibility of realizing a pinhole-type parallax barrier display, and we described a spinning-disc television system that is capable of displaying multiple parallax images.

We developed a prototype television system which has a 64 × 64 pixel screen and is capable of displaying 64 parallax images at the same time.

Our system was exhibited at a conference and feedback was collected from the observers. It was confirmed that our system is capable of successfully displaying 3D images. In order to improve the camera unit, we plan to replace the current PD component with a higher sensitivity PD. This will enable our system to produce more realistic 3D images.

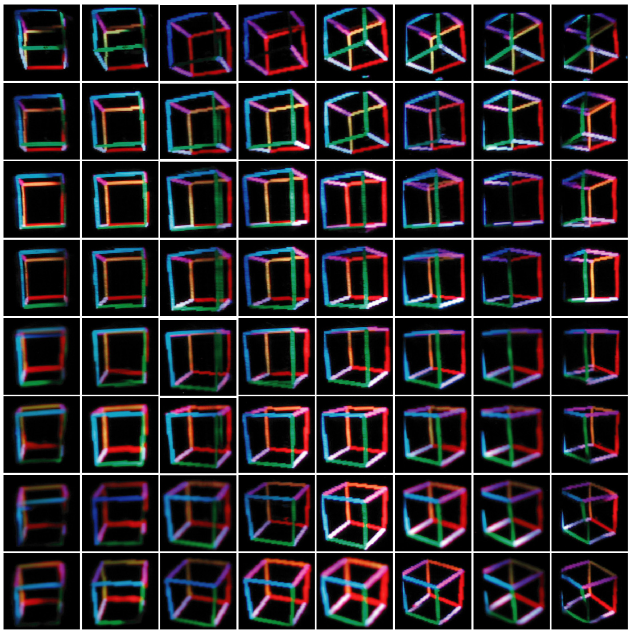

Figure 15: Photograph of display images from 64 view points.

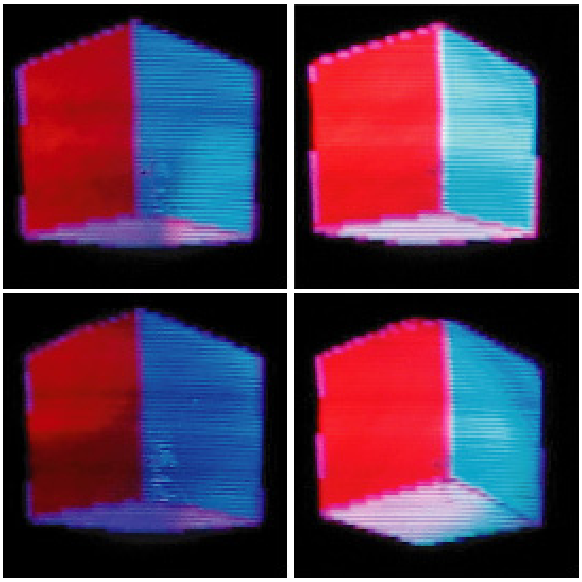

Figure 16: Photograph of display images of a solid cube.

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