3D Display with Expanded Viewing Zone and Virtual Full-parallax for Mobile Devices

We have prototyped a 3D display that is capable of presenting natural three-dimensional images that do not require special glasses for viewing. By determining viewer's position from the camera image and changing the 3D image that is displayed real-time, it makes it possible to achieve a virtual full-parallax display that features a smooth motion parallax effect in both the up-down and left-right directions. This research was conducted jointly with Takaki laboratory (Associate Professor Yasuhiro Takaki), the Department of Electrical and Electronic Engineering, Tokyo University of Agriculture and Technology.

Masashi Tsuboi and Tsutomu Horikoshi

1. Introduction

The rapid development of mobile terminals, portable game devices and other mobile devices of recent years has resulted in displays that have greater detail and higher resolution, and can thus present more information. On the other hand, there is rising expectation for further increase in the added value of video contents, and experiments on 3D contents distribution to a mobile terminal (SH505i) have been conducted[1].

We have previously proposed a mobile 3D display terminal that achieved a smooth motion parallax[*1] effect in the horizontal direction[2][3]. However, this prototype had a narrow viewing zone[*2] of about 30 degrees in the horizontal direction and did not achieve vertical parallax[*3]. To solve these issues, we focused on the point that mobile displays are generally used by a single viewer, and chose an approach in which the viewer's position relative to the display is estimated by using a camera or an inclination sensor. This information is then used to dynamically change the 3D image according to the viewing position. With this approach, we made a prototype mobile 3D display terminal that has twice the horizontal viewing zone of the previous prototype and achieves motion parallax in the vertical direction as well. In this article, we describe the principles to achieve the expanded viewing zone and vertical motion parallax. We also demonstrate the actual achievement of the parallax effect in a 60-degree horizontal viewing zone and a 30-degree vertical viewing zone with a new prototype.

2. High-density Directional Images Method for 3D Display

A high-density directional images method was developed to implement an eye-focusing function and a 3D display method that features a smooth motion parallax effect[4]. Specifically, a lenticular sheet was attached to an ordinary liquid crystal display at an angle to implement images that are directional and have high density in the horizontal direction[5]. The lenticular sheet comprises cylindrical lens arranged in parallel (**Figure 1**).

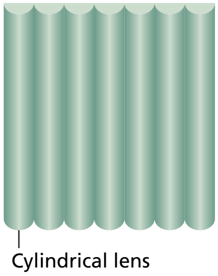


Figure 1 Lenticular sheet

[*1] Motion parallax: The change in the way an object is seen due to movements of the head. It is one factor in human 3-D vision.

[*2] Viewing zone: The range within which video can be seen when watching a display. In this article, it refers particularly to the area within which natural 3-D image can been seen.

[*3] Parallax: The difference in an image as seen from the different viewing position. Especially, the difference between the left and right eyes is referred to as binocular disparity. In this article, we refer to binocular disparity and motion parallax as parallax.

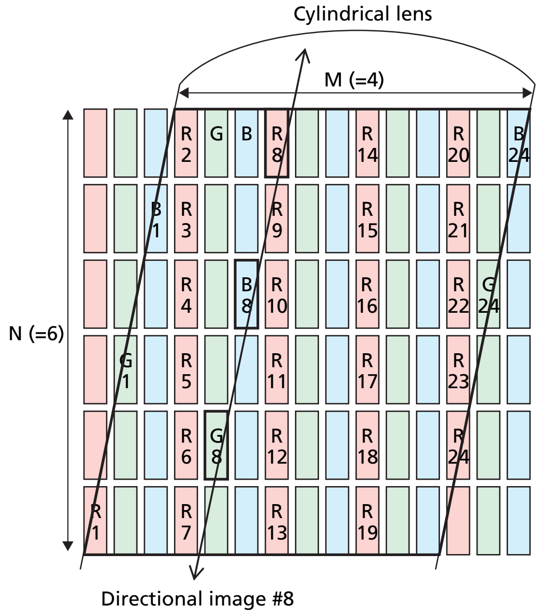


Figure 2 Principle of the high-density directional images

The sheet is concave-convex in horizontal cross section and acts as a lens in the horizontal direction, but passes light through as a simple glass in the vertical direction.

The principle of this method is shown in **Figure 2**. If we turn attention to a single cylindrical lens on the liquid crystal display, the pixels on the back surface of the cylindrical lens are cut into parallelograms, and the direction of the rays of light from those pixels is controlled by the cylindrical lens. The pixels that are cut into parallelograms shown here are 3 N × M in size, and the effect of the lens function is to project N × M different full-color directional images. In the example shown in Fig. 2, M = 4, N = 6, and 24 images that are horizontally directional are projected. The R1 to R24 in Fig. 2 are the red pixels of the liquid crystal display for the 24 directional images. The blue and green pixels are similarly represented as B1 to B24 and G1 to G24.

We combined a 7.2 inch liquid crystal display and the lenticular sheet to make a prototype 3D display for mobile use that displays 30 (M = 5, N = 6) directional images[2]. The prototype specifications are shown in **Table 1**.

The prototype 3D display is capable of smooth horizontal motion parallax within a viewing zone of 28.1 degrees. Such a narrow viewing zone is inadequate, however, because if the viewer moves one head-width distance to the left or right, he exits the viewing zone. As the viewer moves from inside the viewing zone to outside the viewing zone, the 3D image he sees is repeated a number of times. This effect is referred to as a repeating image, and it poses an issue for high-density directional images methods and other binocular stereoscopic displays that present 3D images by means of multiple images.

Table 1 3D display specifications

Number of directional images	30 (M = 5, N = 6)
Directional image display angle gradation	0.94°
Viewing zone	28.1°
3D resolution	256×128pixels

In this system, a lenticular sheet is positioned against the display at an angle relative to the vertical, thus creating high-density directional images in the horizontal direction. Put another way, we could say that the density of color pixels in the vertical direction is sacrificed for increased density for the display of directional images in the horizontal direction. Therefore, this system configuration makes it difficult in principle to display directional images in the vertical direction at the same density as in the horizontal direction, thus also making it difficult to achieve vertical parallax.

3. Principle of Viewing Zone Expansion

To solve the issue described above, we propose a method of expanding the horizontal viewing zone by detecting or inferring the viewer's position, and achieving motion parallax in the vertical direction.

3.1 Expansion of Viewing Zone in the Horizontal Direction

Our 3D display prototype had smooth motion parallax, but a narrow viewing zone of about 30 degrees. This was an issue if the viewer moved out of the viewing zone and saw repeating images as a result. The repeating image effect occurs because of the change in pixels that are observed through the lens as the viewer changes position. The principle of repeating image generation is shown in **Figure 3**.

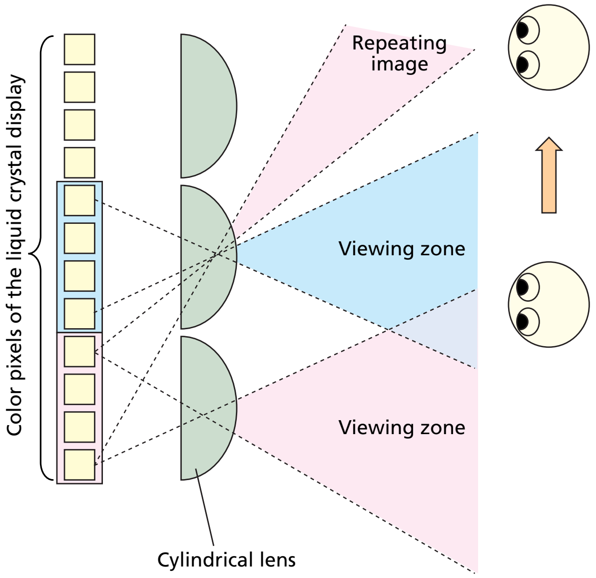


Figure 3 Principle of repeating image generation

In Fig. 3, the liquid crystal display and the lenticular sheet are shown, and the viewer is looking down on the liquid crystal display and lenticular sheet. When the viewer is within the viewing zone, the pixels on the liquid crystal display are seen through the cylindrical lenses that constitute the lenticular sheet. Here, when the viewer moves out of the viewing zone, the pixels that are seen through the cylindrical lens may be different. This is the reason that the repeating image may be seen a number of times by a viewer who is outside the viewing zone.

If we assume a single viewer, the viewing zone can be expanded by dynamically changing the video image that is displayed according to the viewer's position. Our new prototype 3D display has the same 30-degree horizontal viewing zone as the previous prototype, and considering the use environment of ordinary mobile devices, this viewing zone includes at least the distance between a viewer's two eyes. Therefore, if it were possible to redraw the image before the viewer moves to the edge of the viewing zone, it would be possible to expand the viewing zone by changing the video image without the viewer becoming aware of the change.

3.2 Achieving Virtual Full Parallax

Although the high-density directional images method is capable of high-density directional display in the horizontal direction, the structure of the lenticular sheet makes it difficult to achieve vertical parallax at the same time. Here, if we assume a single viewer, a vertical motion parallax effect can be achieved by altering the 3D image according to the relation between the 3D image and the position of the viewer in the space in front of the display. A 3D display that adopts the high-density directional images method has inherent horizontal motion parallax, always presenting 3D image to the two eyes. Thus, a natural 3D display is possible unless the viewer's head is tilted relative to the display, and a virtual full-parallax effect in the up/down and left/right directions display can be achieved.

4. Prototype System

We used the high-density directional images method described in Chapter 3 and a method of estimating the viewer position to implement a 3D display that has an expanded horizontal viewing zone and achieves the virtual full-parallax effect. The viewer's position is estimated by using the image from a camera that is attached to the display to track the viewer's face, and an inclination sensor to measure the position of the display. We implemented these methods to construct a prototype system.

First, we will explain how the viewer's face is detected from the camera image and tracked[6]. We used a USB camera attached at the top of the display to detect the positions of the viewer's two eyes in the camera image. The amount of detected movement of the eyes was used to alter the video display to a corresponding degree.

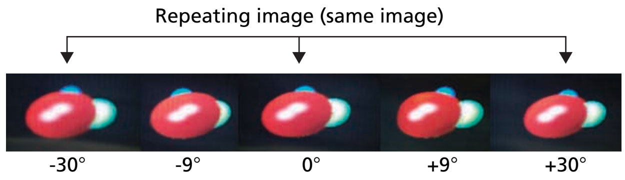
The inclination sensor was also attached to the display, and its output was used to switch the video display according to the display's angle of inclination. The inclination sensor used in this prototype is capable of measuring inclination with respect to the earth's axis to within an error of 1% for inclinations of 65 degrees or less.

The viewer positioning system was implemented with these two methods. Specifications that show the effects of applying each of the two methods are shown in **Table 2**.

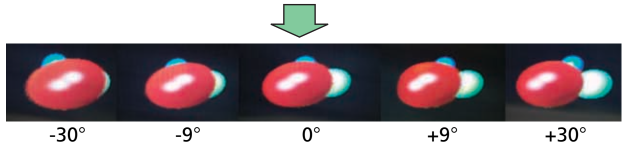
The processing speeds discussed here are for a Pentium D 3.2 GHz computer with 2 GB of memory. When the camera

Table 2 Determining the viewer's position

	Camera image	Inclination sensor
Detection range	±30°	±65°
Processing speed	29.9 fps	58.5 fps
Robustness against changes in the external environment	Low	High
Adaptation to viewer movement	Possible	Not possible
Adaptation to tilting of the display	Possible	Possible



(a) No expansion



(b) Expansion

Figure 4 Expansion of the horizontal viewing zone

image was used, the processing was relatively slow, and the detection range was limited by restrictions such as the view angle and resolution of the camera lens. The camera detection system is also subject to variations in environmental conditions such as level of illumination. When the inclination sensor is used, on the other hand, processing is fast and the detection range is large. Nevertheless, the viewer's position cannot be determined from the display inclination alone. Thus, each of the two methods has its advantages and disadvantages, and neither can be identified as unconditionally superior. For this prototype, we implemented both the camera image method and the inclination sensor method independently, and succeeded in achieving both a broader viewing zone and vertical motion parallax.

To show the effect of the expanded horizontal viewing zone, the 3D video image displayed by the previous system taken while moving the camera in the horizontal direction image is shown in **Figure 4** (a) and with the horizontal viewing zone expansion implemented in Fig. 4(b).

With the previous system, repeating image occurs at ±30 degrees, and the same image is seen as is seen from the 0-degree position (Fig. 4 (a)). We can see that applying the method we propose expands the viewing zone by varying the video image according to the position of viewing within the range of ±30 degrees (Fig. 4 (b)).

The result of implementing vertical motion parallax is shown in **Figure 5**. As the viewing position moves up or down and left or right, natural 3D image can be seen in accordance with the viewer's movements.

5. Conclusion

Making use of the feature that mobile terminals are generally used by only a single viewer at a time, we adopted a method of estimating the relative positions of the viewer and display and using that information to vary the video display so as to achieve virtual full-parallax 3D video display. The expanded

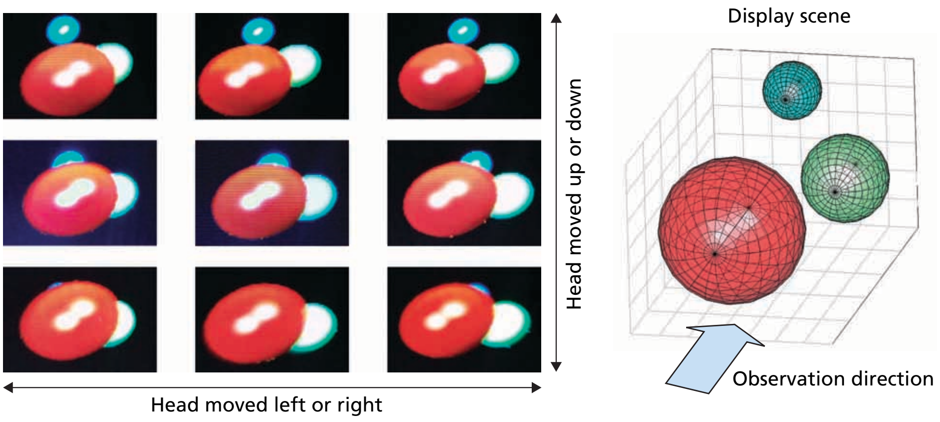


Figure 5 Achieving vertical motion parallax

horizontal viewing zone and vertical motion parallax were realized by a prototype device.

We will continue with work on 3D video for mobile communication and methods of achieving interactive 3D video that features a 3D interface. We will also proceed with research on 3D photography and conversion of video to 3D.

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