

## Multi-View Glass-Less 3-D Display by Parallax Barrier of Step Structure

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### Synopsis

The parallax barrier of step structure (step barrier) technology with multiple parallax images has overcome the problem of conventional parallax barrier system that the image quality of each image deteriorates only in the horizontal direction. The step barrier distributes the resolution reduction both to the horizontal and the vertical directions. The system has a simple structure, which consists of a flat-panel display and a step barrier. The apertures of the step barrier are not stripes but tiny rectangles that are arranged in the shape of stairs, and the sub-pixels of each image have the same arrangement. We also proposed three image processes suitable for the step barrier system, and then developed two types of 3-D displays, 7-view 22-inch model of 3840 x 2400 pixels and 4-view 50-inch model of 1280 x 768 pixels.

KEYWORDS: 3-D display, Stereoscopic, Multi-view, Step barrier, Parallax barrier, Resolution, Moire

### 1. Introduction

Three-dimensional (3-D) displays using special polarized glasses or shutter glasses are already reaching perfection. However, an ideal is to view stereoscopic images without these special glasses, and various techniques and systems of glass-less 3-D displays are proposed. A parallax barrier system<sup>1)</sup> and a lenticular lens system<sup>2)</sup> are well known systems to let people easily view stereoscopic images without special glasses. In these systems, parallax images are separated by the plurality of vertical stripe shaped slits or lenses. But there are some problems. At first, that stereoscopic viewing area is narrow. Next, moire occurs between the optical filter and the display device. And then, the images do not change when the viewer moves.

To solve them there are two approaches. One is the head tracking system and the other is the multi-view system. The head tracking system has a sensor to detect viewer's head position and keep the condition of the 3-D display proper for the viewer according to the head position<sup>3)4)</sup>. So the stereoscopic viewing area widens and the moire is scarcely observed. This method also has the feature that resolution does not deteriorate so much. But it does not provide stereoscopic images for many persons at the same time because there are only two images, and they are adjusted for only one viewer.

On the other hand, the multi-view system provides more than two images. This widens the stereoscopic viewing area and two or more people can see stereoscopic images at the same time. Furthermore, the images are more natural than other methods because the images change according to the viewer's movement. And recently, progresses of the high performance personal computers and the high-resolution flat-panel display devices accelerate the development of the multi-view systems. They are usually based on the conventional two-view systems, but it is necessary to improve the resolution and the moire problems. The techniques based on the parallax barrier system to hold resolution balance between the horizontal and vertical direction and to reduce moire problem will be described below.

### 2. Step Barrier System

#### 2.1 Multi-view system

The multi-view system has a simple structure, which consists of a flat panel display device and a parallax barrier. Figure 1 shows how the system works. In this example, the number of viewing points is four and four images are prepared. Image1, 2, 3, and 4 are the slightly different images shot by four cameras placed at different positions one another to give the images proper parallax. Otherwise, they can be created on the computer graphics by the same manner. The format converter takes these images apart into elements of sub-pixel size and arranges them on the display screen repeatedly in the same order as the camera position. Then, the parallax barrier is placed on the display device so as to separate the image viewing areas through

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minute apertures. The apertures are formed on the glass substrate and each aperture is corresponding to one group that consists of the four adjacent elements of different viewing points. In this manner, there occur image viewing areas from where only each of the image1, 2, 3, or 4 can be seen according to the position. At the proper viewing distance, the width of the each area is designed to 65 mm that is the average distance between left and right eyes. So, when the viewer sees the display from where the right eye is in the image2 area and the left eye is in the image3 area, the viewer can recognize a stereoscopic image, because it is the equivalent situation that the viewer has a place of the camera2 and 3. It is the same for the pair of image1 and 2, or 3 and 4. And only the area of the pair of image4 and 1 is a pseudo-stereoscopic zone. Thus the viewing area widens compared to the conventional two-view system.

Moreover, the viewing area becomes larger to the back and forth direction. Figure 2 shows an example that the viewer sees at the much shorter distance than the proper viewing distance. Obviously this position is outside the viewing area on the two-view system. However the viewer sees the image2 and 3 on the center of the screen, image1 and 2 on the left side of the screen, and image3 and 4 on the right side of the screen on the four-view system. They are different pairs but stereoscopic pairs, so the viewer can see the stereoscopic images there. In the multi-view system, the different stereoscopic pairs can be mixed on the display screen like this even if the viewer sees the display from non-proper distance. After all, average rate of the pseudo-stereoscopic zone in the whole screen is one n-th, where “n” is number of the viewing points. This means that the larger the number of viewing points is, the larger the viewing area becomes.

But the conventional parallax barrier system has a problem that image quality of each image deteriorates only in the horizontal direction due to the stripe shaped apertures. Figure 3(a) shows a structure of the conventional parallax barrier of four-view system and figure 3(b) shows the corresponding image displayed on the screen. Sub-pixels that have the same view number and the same color are arranged in the vertical line. Figure 3(c) shows the example of the condition that the parallax barrier is placed on the display device and

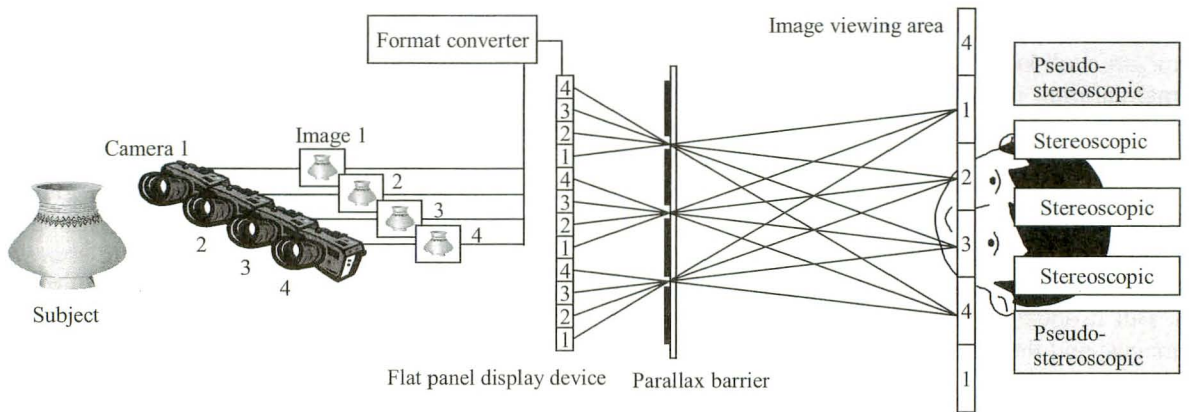


Fig.1 Principle of a four-view camera and display system.

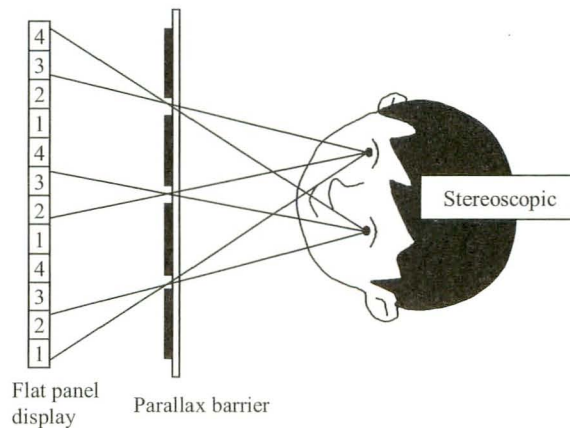


Fig.2 The condition that the viewer sees the stereoscopic images at the much shorter distance than the proper distance.

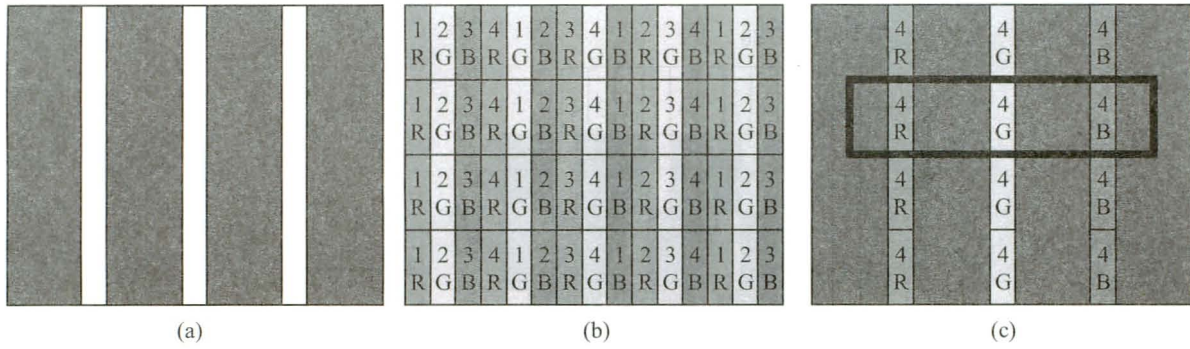


Fig.3(a) Structure of the conventional parallax barrier. (b) Viewing point numbers given to the sub-pixels on the display device. (c) Condition that the image4 is seen through the apertures.

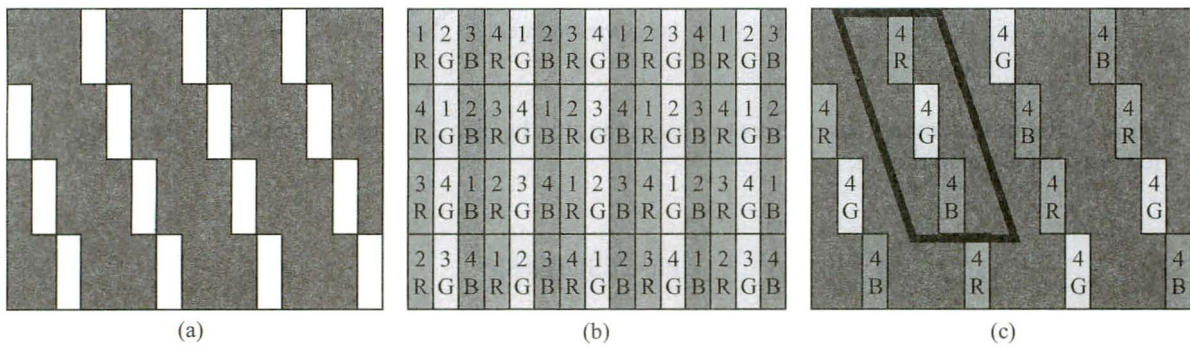


Fig.4(a) Structure of the conventional parallax barrier. (b) Viewing point numbers given to the sub-pixels on the display device. (c) Condition that the image4 is seen through the apertures.

image 4 is seen through the parallax barrier by an eye. Each image element of the vertical line has the same vertical quality as the original display resolution. On the other hand, the image elements appear every four columns horizontally and it can be considered that the three detached red (R), green (G), and blue (B) sub-pixels constitute a pixel enclosed by the bold line. So the quality of each image deteriorates to one-fourth the original display resolution in horizontal direction. Generally, the deterioration is one  $n$ -th. It is to say that the pixel aspect ratio of an image is 1 to  $n$  and the balance of the resolution is not suitable. This problem becomes still more remarkable as the number of the viewing point increases.

### 2.2 Step barrier technology

The step barrier technology has overcome the shortcoming of the conventional system. The step barrier distributes resolution reduction both to the horizontal and the vertical directions. The system has a similar structure to the conventional one except the shape of apertures. As shown in figure 4(a), they are not stripes but tiny rectangles located in slant lines like stairs. Figure 4(b) shows the image displayed on the screen and the sub-pixels of each image are also arranged in the slant lines like stairs. Figure 4(c) shows the example of the condition that image 4 is seen through the step barrier by an eye.

Now, it is suitable to treat a set of red, green, and blue sub-pixels that align near one another in the slant direction as one pixel enclosed by the bold line in figure 4(c). So, the image quality deteriorates to one-third the original display resolution in the vertical direction and to three-fourth in the horizontal direction. Generally image quality deteriorates to one-third the original display resolution in the vertical direction and to three  $n$ -th in the horizontal direction. And the pixel aspect ratio of an image is 9 to  $n$ . If  $n$  is larger than 3, this ratio is always much closer to the ideal ratio, 1 to 1 than that of the conventional system. Thus, deterioration of the horizontal resolution is reduced even if the number of the viewing point increases, and the resolution balance is held.

### 2.3 Design of aperture pitches

The step barrier should be designed to separate the image viewing areas properly. First, the horizontal aperture pitch in the same row "Ph" is expressed as the equation (1) where "Sh" is the horizontal sub-pixel pitch, and "E" is the average distance between the eyes.

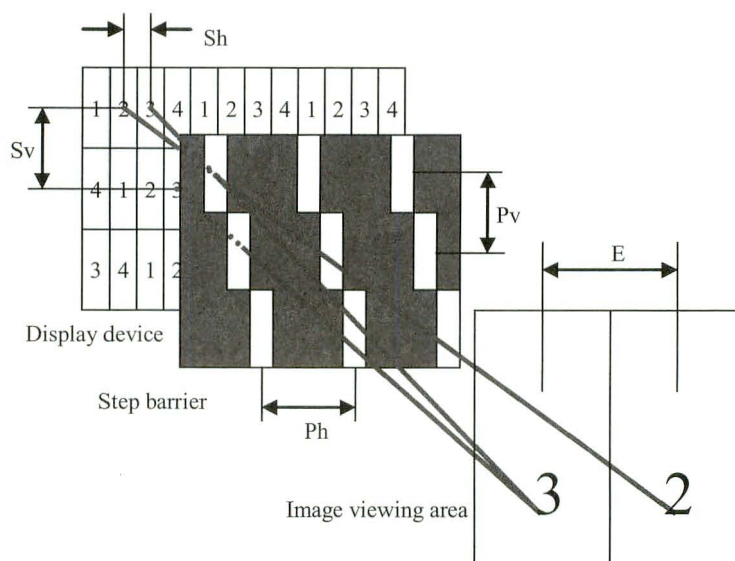


Figure 5. Relations among parameters to design the step barrier. The representatives of the image viewing area are also drawn.

$$Ph=2ESh/(E+Sh) \quad (1)$$

Then, the vertical aperture pitch “Pv” should be designed. It is shown as the equation (2), where “Sv” is the vertical sub-pixel pitch.

$$Pv=ESv/(E+Sv) \quad (2)$$

Although this is meaning that the image viewing area is separated not only in the horizontal direction shown in figure 1 but also in the vertical direction, it does not causes serious problem, because the different stereoscopic pairs can be mixed on the display screen in the multi-view system described above. So the average rate of the pseudo-stereoscopic zone in the step barrier system is the same value, one n-th as the conventional system.

#### 2.4 Design of apertures

This kind of 3-D display usually causes a problem about image quality due to moire. The moire appears by interference between the barrier pattern and the black mask of the display device. It is serious especially when the viewer sees the display at the non-proper viewing distance like the position shown in figure 2. In the case of the figure 2, if the brightness is not uniform in the screen, the advantage of the multi-view system is spoiled remarkably. It can be reduced geometrically by optimum design of the aperture width. However it is not enough, for the diffraction disturbs it. The light rays that go through near by the edge of the apertures are turned and the hidden sub-pixel is seen a little. It causes the slight moire. To solve it, the design of the aperture shape has been modified into non-rectangle and there should be optimum shape according to the shape of sub-pixel. For example, the shape of parallelogram reduces the influence of the diffraction effectively if the sub-pixel has the rectangle shape.

### 3. Image Process

The multi-view image process consists of an image creation part to make up a set of the multi-view images and a format conversion part that composes the stereoscopic image from the multi-view images. This time, three processes are thought out that are selectable according to the system environment. The first method is to get the composed image in highest quality by thinning out but requires high performance systems. The second method is economical type that demands lower performance to the system, but the quality of the composed image is sometimes not so good. And the third is a technique between the first and the second that improves the image quality of the second.

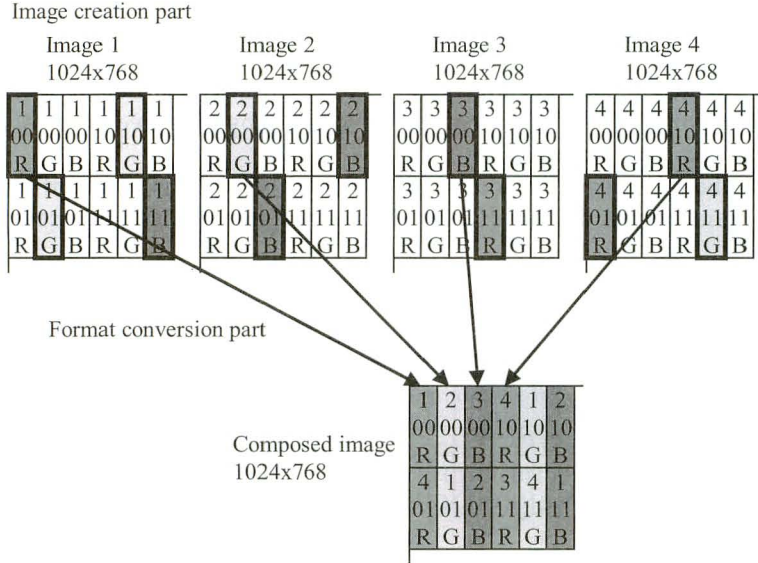


Fig.6 Process of the thinning out method. The upper number in the sub-pixels is the viewing point number and the middle numbers are x and y coordinates of the sub-pixels.

### 3.1 Thinning out method

The first method is the thinning out. The image creation part makes multi-view images in the same resolution as the composed image shown in figure 6. In this case, the resolution is 1024x768 (XGA). And in the format conversion part, proper sub-pixels are selected from the multi-view images and arranged on the composed image. The selection can be done by the below equation (3).

$$H(x,y,c)=Gm(x,y,c) \quad (3)$$

$$m=1+(3x+c-y\%n)\%n$$

$H(x,y,c)$ : Sub-pixel data of composed image.  
 $Gm(x,y,c)$ : Sub-pixel data of multi-view images.  
 $x,y$ : Pixel coordinates.  
 $c$ : Color. (0; R, 1; G, 2; B)  
 $n$ : Total number of viewing points.  
 $m$ : Viewing point number of the multi-view image.  
 $\%$ : Operator that calculates a surplus.

This way provides the best image quality because the coordinates of the sub-pixels do not change before and after the format conversion. But this method has the problem that only the one  $n$ -th of the sub-pixels is used and a large number of sub-pixels are useless although the high quality is required to the multi-view images.

### 3.2 Waste-less method

Sometimes the image creation part will be restricted. For example, rendering the images for number of viewing points gives a stress to the computer. And in the case of multi-view real photographs or movies, the limit is decided by the resolution of the image sensor. So it is difficult to get high quality multi-view images. The second technique is to solve this. It is the waste-less method applying the point of view about the pixel constitution mentioned in chapter 2.2. As shown in figure 7, the image creation part makes multi-view images in the resolutions of one-fourth the composed image. Strictly, the vertical resolution is one-third and the horizontal resolution is three-fourth the composed image. In this case, the resolution is 768x256. And then, all the sub-pixels are used to make up the composed image without any waste in the format conversion part. At this time, equation (4) is to select sub-pixels.

$$H(x,y,c)=Gm(x0,y0,c) \quad (4)$$

$$x0=(3x+c-y\%3)/n$$

$$y0=y/3$$

This is the efficient image process but the quality is sometimes insufficient when the resolution of the composed image is not so high like this case. This is caused by disagreement of the coordinates of the sub-pixels before and after the format conversion.

The true effect is got when the display resolution is extremely fine. This was confirmed by the system using a very high-resolution liquid crystal display (LCD) shown in figure 8. This is a seven-view system and the

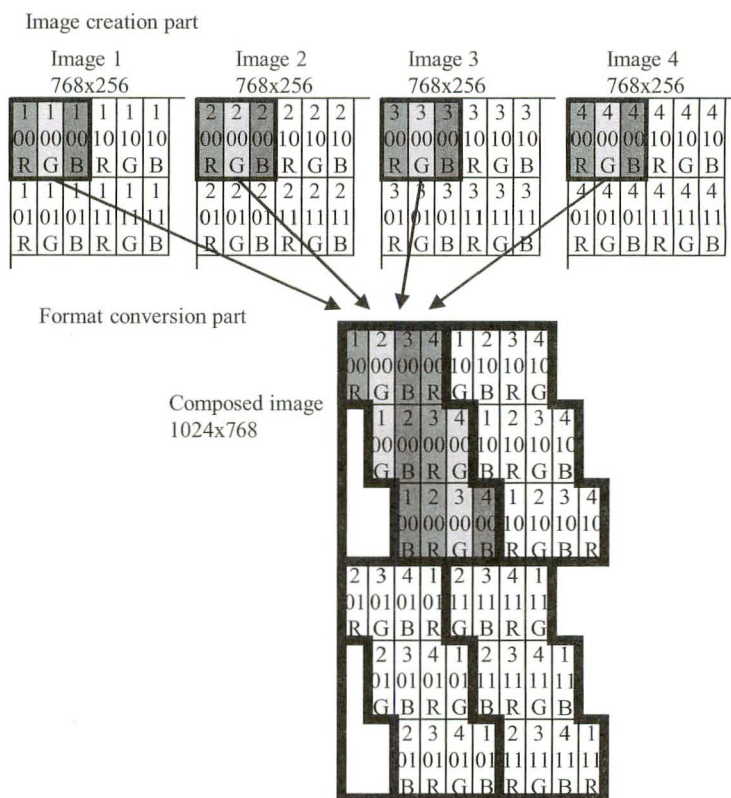


Fig.7 Process of the economical method.

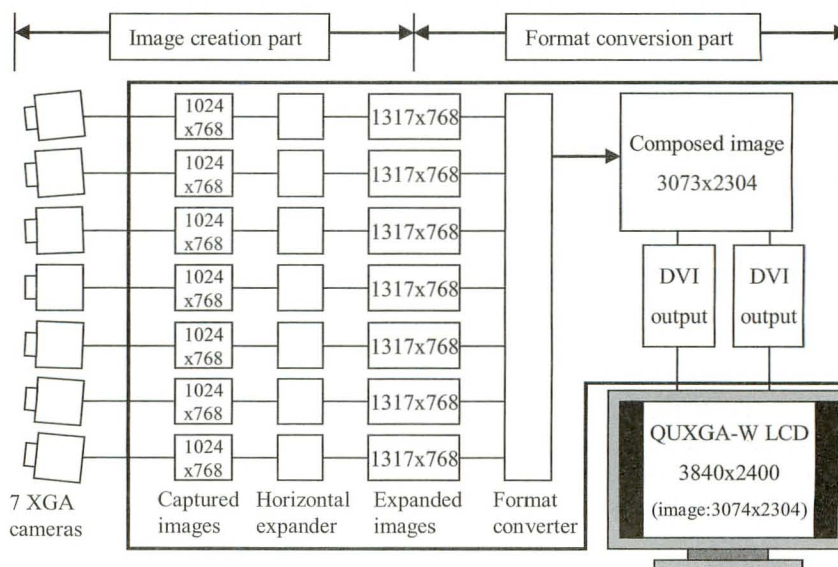


Fig.8 Example of the Waste-less method for the real image camera system.

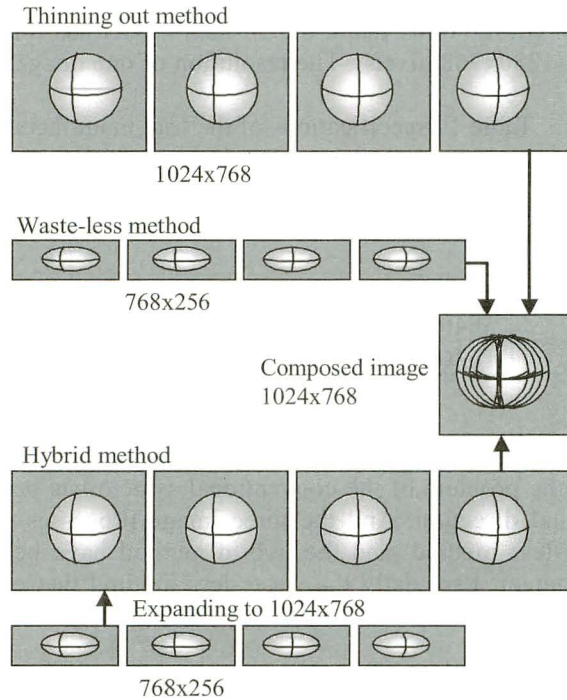


Fig.9 Third method and comparison of three methods.

resolution of the multi-view images captured by seven cameras is XGA. The horizontal expander changes the pixel aspect ratio into 9 to 7. Then the images are composed into a high-resolution image of 3073x2304 without any waste. And the image is displayed on the seven-view 22-inch QUXGA-W display. In this system, since the sub-pixel pitch of the display is very small, the coordinate disagreement does not cause any problem.

### 3.3 Hybrid method

Figure 9 explains the third method comparing with the other methods. It is the mixed technique of the above two that improves the resolution of the second method. In the image creation part, the multi-view images are created by the second method, and the images are enlarged into the composed image resolution. Finally, the composed image is made using the thinning out of the first method by the equation (3) in the format conversion part. By the way, the multi-view images of the second and the third methods are strained to the vertical direction. It is because the pixel aspect ratio of the images is not 1 to 1.

## 4. Trial manufacture

Two types of 3-D displays have been developed, 22-inch model (figure 10) and 50-inch model (figure 11). The 22-inch model employs a very high-definition LCD of QUXGA-W (3840x2400 pixels). The number of



Fig.10 22-inch 3-D display.

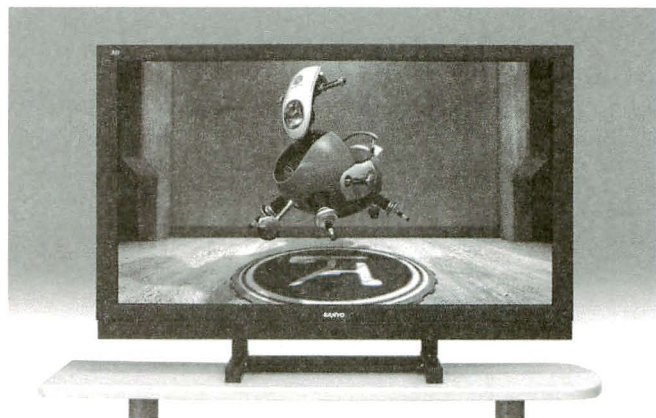


Fig.11 50-inch 3-D display.

viewing points is seven and the resolution of one image is approximately 1646x800 pixels. It is used for the real image system shown in figure 8. On the other hand, the 50-inch model has four viewing points on the plasma display panel (PDP) of W-XGA (1280x768 pixels). The resolution of one image is 960x256 pixels.

Table 1. Specifications of the trial manufactures.

Screen size	22 inches	50 inches
Active area	478.1mm x 298.8mm	1098.2mm x 620.5mm
Viewing points	7	4
Viewing distance	Typ:930mm	Typ:1190mm
Number of pixels (original)	3840x2400	1280x768
Number of pixels (one image)	1646x800	960x256

### 5. Conclusions

By the step barrier technology, the deterioration of the image quality is distributed both to the horizontal and the vertical directions, and the problem of the conventional system has been overcome that image quality deteriorates only in the horizontal direction. And the three image processes for the step barrier system, the thinning out method, the waste-less method, and the hybrid method have been proposed that are selectable according to the system environment. Especially the waste-less method that can compose the high-resolution image from the multi-view image of usual resolution realizes the high-resolution real image systems. Then two trial manufactures have been produced.

These technologies makes 3-D displays applied in various uses. They can provide additional impression in the entertainment machines and the personal computers. They will give new solution in the computer added design (CAD) systems, the visualization systems like protein structural analysis, and the digital archive use. The exact information might change the education. The electric signboard and the information display will get more attentions. Furthermore, new expression will be born in arts. And finally, it is expected that the day when the home stereoscopic televisions are realized come.

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