Continuous depth expression in double-layer 3D display

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Abstract

A method to make the near and far images for a double layer 3D display system to create continuous depth illusion has been studied. The luminance ratio between the near and far images should be allocated based on the tone reproduction characteristics of the display systems.

1. Introduction

It is well known that double-layer display is an effective way to produce 3D illusion [1], [2]. Two image planes, front and rear, containing images of near and far objects, respectively, provide depth illusion. Since no mismatch between accommodation and convergence is required in the method, eyestrain of viewers can also be minimized comparable to ordinary 2D displays [3]. It has also been known that continuous depth illusion is also achievable with the method [4]. Viewers see the object displayed on both front and rear screens simultaneously as if the object locates in between the screens as shown in Fig. 1. The relative position of the perceived image of an object is determined by the luminance ratio between the images on the front and rear screens, where the luminance ratio is assigned corresponding to the depth information of the object.

It was found that the naturalness of the image strongly depends on the way to assign the luminance ratio between the near and far images. In particular, the luminance of the combined image varies significantly as the corresponding objects move back and forth if the luminance allocation is improper. In this paper we present a systematic method of assigning luminance levels to the images on the front and rear screens corresponding to the depth information of the objects. The double-layer displays with binary and continuous depth expression have been compared.

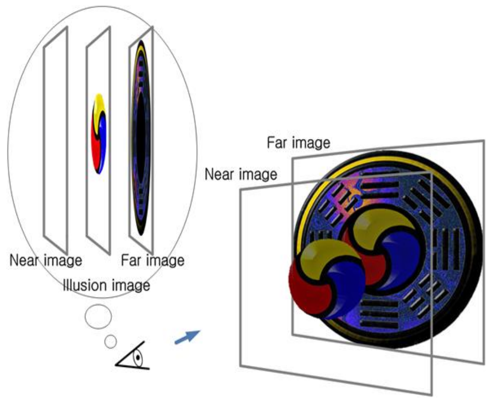

Fig. 1. Principle of continuous depth illusion.

2. Luminance assignment

As a 2D image data and its depth information are given, the image is separated as one for the front screen and another one for the rear screen. Meanwhile, the luminance levels of the near and far images should be summed up to make that of the original image, and the ratio between the luminance levels is to be determined to present depth illusion. Since the input(video data) and the output(luminance level) of a display system is normally nonlinear, luminance levels for the near and far images should be assigned based on the Tone Reproduction Curve(TRC) of the display systems.

Figure 2 describes the method of assigning luminance levels for the near and far images. If an object with a luminance data of D_o corresponding to a luminance level of L as shown in the figure locates at a distance of 70 % to the background image plane from the viewer, its images on the front and rear screens will be given luminance levels of L_N and L_F, respectively. The ratio between the levels is given by L_N:L_F =3:7. The luminance levels are then converted into the image data D_N and D_F for the front and rear screens, respectively.

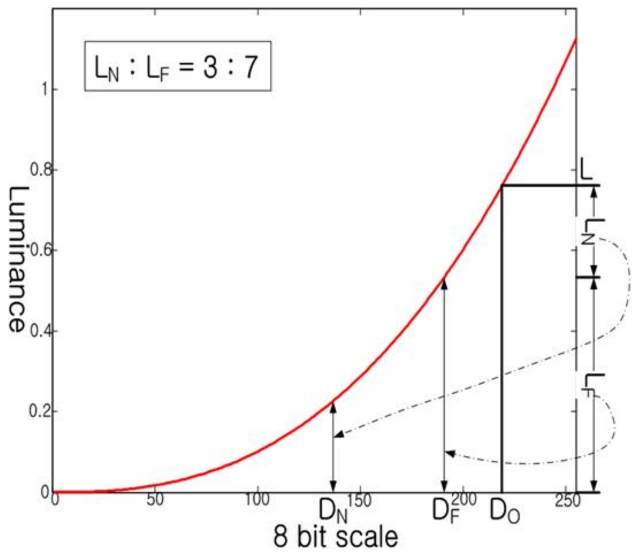

Fig. 2. Luminance division based on TRC of front and rear screens.

Figure 3 shows the measured TRC's of the test setup consisting of two LCD panels and a half-mirror. The measured TRC's can be represented by a well known mathematical model formula given as follows

$$L = aV^{\gamma} \quad (1)$$

where V is the video input to the panel in 8-bit binary scale, and a=230^{-3} and γ=3 are extracted fitting parameters. The luminance level is normalized to have a maximum value of unity.

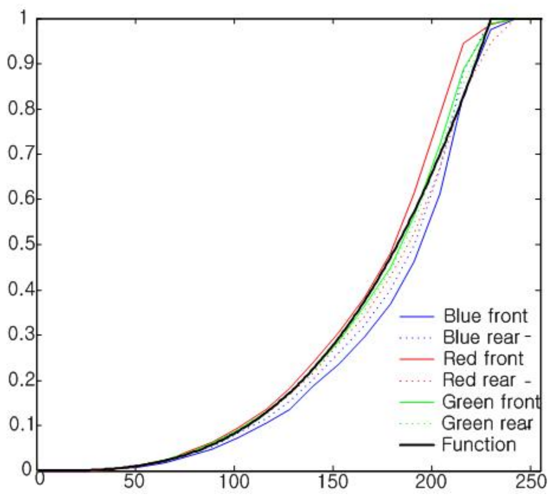

Fig. 3. TRC of using two LCD monitors and half-mirror.

The input data for the front and rear screens can be found using the inverse of the formula (1). As the luminance level for a screen is given, the input data for the screen is given by:

$$V = (L/a)^{1/\gamma} \quad (2)$$

where V is the video input, which is to be converted into a binary number for a real application to the display panel.

Figure 4 shows the combined images of near and far images on the front and rear screens, respectively, with different luminance ratios. Although it is not visible from the figure, the circular Taegeut patterns at the centers of the images look as if they locate at different depth from the viewer depending on the luminance ratio between the near and far images. As can be seen from the figure, no considerable difference in luminance level is seen. Additionally, it has been found that the luminance level stays almost unchanged even when the object moves back and forth continuously.

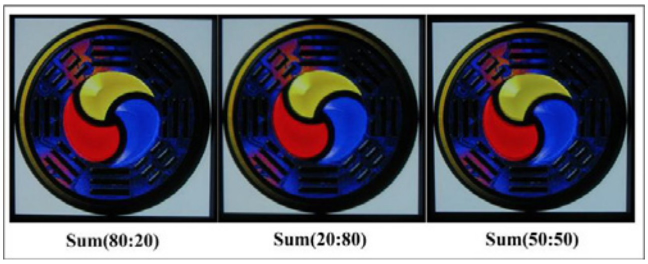

Fig 4. Combined images of near and far images with different luminance ratios look identical.

3. Elimination of shadow-effect

The binary-depth double-layer display method has many advantages such as ease of creation and reproduction of image data, possibility of keeping the compatibility of transmission channel format with conventional TV, and high degree of cleanness of displayed image. However, the binary-depth system has a drawback of unnatural shadow-like artifact caused by a misfit between the front and rear images when seen at a tilted angle as shown in Fig. 5. The upper part of Fig. 5 shows the dark part at the edge of the circular object on the front screen.

The so-called shadow effect can be eliminated by duplicating the images on the front screen simultaneously on the rear screen. This can be done by using a continuous-depth method and by exaggerating the depth information of the edges of the front objects. The lower part of Fig. 5 shows the images with the shadow effect eliminated. Apparently, the cleanness of the image corresponding to the objects on the front screen is reduced.

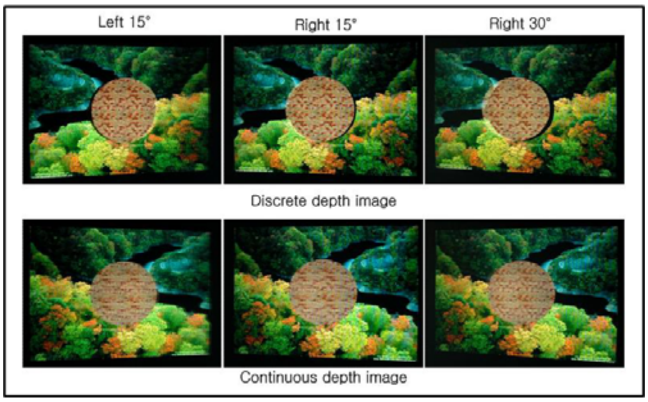

Fig 5. Images seen at various tilted angles.

4. Conclusions

A method to assign an optimal luminance ratio between the pixels in the near and far images based on the TRC of display system and the depth information of the object corresponding to the pixel was developed. A systematic approach to create near and far images based on the depth information of the corresponding objects in the images has been developed for the double-layer 3D display systems. The visual performance of the system was found to be improved significantly using the method. It is believed that this work will boost the advance of the multilayer display technology toward the commercial applications. It is also believed that the study will play a significant role in understanding the human factors related on the multilayer 3D displays

Acknowledgements

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