Evaluation of Linear Blending between View Images and Depth Perception by Monocular Motion Parallax in Visually Equivalent Light Field 3D Display

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ABSTRACT

We have achieved linear blending of adjacent view-image luminances and appropriate monocular perceived depth by smooth motion parallax in a Visually Equivalent Light Field 3D display. Multi-view images at several positions are confirmed to have almost linear luminance change by horizontal position change. Smooth motion parallax with a single eye provides almost the same monocular perceived depths as designed depths.

1 INTRODUCTION

Recently, various 3D displays without wearing 3D glasses have been proposed to provide high realism. Besides binocular disparity and vergence, smooth motion parallax according to the observation position change is also important for high realistic sensation. However, in order to satisfy smooth motion parallax by using super multi-view display [1], a sufficiently narrow viewpoint interval and a large amount of multi-view images are required.

On the other hand, the Visually Equivalent Light Field 3D (VELF3D) display [2] can provide smooth change of multi-view images even by a small number of multi-view images using linear blending technology. This smooth change of multi-view images is expected to achieve appropriate monocular perceived depth by motion parallax.

In this study, we confirm the linear luminance distribution in VELF3D display using linear blending technology and evaluated the monocular depth perception by monocular motion parallax.

1.1 Linear Blending Technology in VELF3D Display

Figure 1 shows a schematic illustration of the linear blending technology. Positions a and b are camera positions in which multi-view images of A and B are taken. In conventional multi-view 3D displays, view image A (B) is designed to display between position a (b) and mid-point of positions a and b. This arrangement leads to flipping of multi-view images around mid-point of positions a and b.

On the other hand, linear blending technology has different arrangement and luminance change as shown in Figs. 1 and 2. Luminance of view image A (B) is linearly and complementarily changed from position a (b) to position b (a), as shown in middle row (optical images) in Fig. 1 and right graph in Fig. 2. This leads to optically double imaging, whose luminances are linearly changed complementarily, as shown in Fig.1. For example, when observation position moves from position a (b) to position b (a), luminance of view image A (B) linearly decreases and luminance of view image B (A) linearly increases.

Optical images are double imaging of view images A and B as shown by middle row in Fig. 1. However, perceived edge positions by human visual system are linearly moved as shown in bottom row in Fig. 1. This is because human visual system uses low-pass filtered images of retinal images for judging perceived depths [2]. This result in that the multi-view images, such as triangles and circles in Fig. 1, move smoothly according to the change in the observation position even when the number of multi-view images is small.

Thus, linear blending technology can provide smooth motion parallax even by small number of multi-view images.

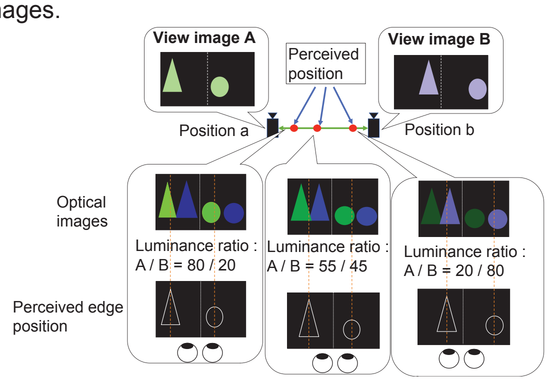


Fig. 1 Schematic illustration of linear blending technology

1.2 Mechanism of VELF3D Display

Figure 2 shows the structure of the VELF3D display. Multi-view images are displayed on the liquid crystal panel in order, such as view images A, B, and C. By arranging a parallax barrier in front of the backlight behind the panel, the area of the backlight is spatially limited. This leads to narrow and slit-shaped illumination of the LCD panel, whose width is the same as the LCD pixel. This results in illuminating specific LCD pixels of the viewpoint image, for example, the image of the viewpoint A.

By utilizing this limited parallax barrier, when the observer moves from the viewpoint A to the viewpoint B, the illuminating area at the image of the viewpoint A in LCD panel decreases linearly and the illuminating area at the image of the viewpoint B increases linearly. This results in linear luminance changes of view images A and B as shown by the right graph in Fig. 2.

For example, when the observation position is moved from the viewpoint A to the viewpoint B, the luminance of the image at the viewpoint A decreases linearly as shown in the right graph in Fig. 2. At the same time, the luminance of the image at viewpoint B increases linearly. At the midpoint between adjacent viewpoints, both two images of adjacent viewpoints are illuminated by backlight. This luminance changes leads to smooth perceived change of view images A and B in human visual system [2].

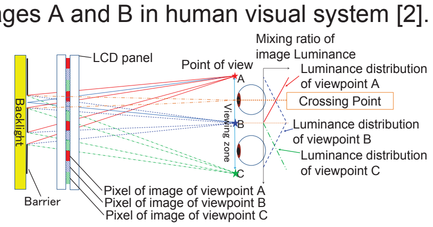


Fig. 2 Mechanism of VELF3D display

2 EVALUATION OF LINEAR BLENDING BY MEASURING LUMINANCE DISTRIBUTION OF MULTI-VIEW IMAGE IN VELF3D DISPLAY

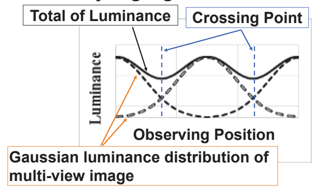
The linear blending of multi-view images in VELF3D display are estimated by measuring luminance distribution of multi-view images using a cooled CMOS camera. In previous study [3], when only one viewpoint is measured with a cooled CMOS camera, the luminance distribution has steep slopes but dull top, which indicates that measuring sharp top by only one viewpoint is difficult because very high resolution is required. In this paper, we propose to utilize characteristics of total luminance distribution of multi-view images for judging the linear blending as follows.

2.1 Total Luminance Difference between Gaussian Distribution in Multi-view 3D Display and Linear Blending in VELF3D Display

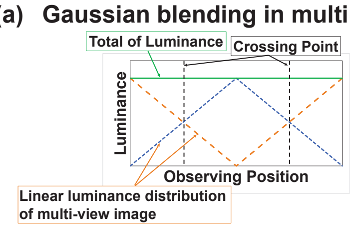
In conventional multi-view 3D display, luminance distribution at one viewpoint has a Gaussian distribution due to crosstalk as shown by broken lines in Fig. 3(a). At crossing point between adjacent view images, this Gaussian distribution leads to the inappropriate small luminance less than 50 % because high contrast ratios at the viewpoints between adjacent view images are necessary. This results in the fluctuation in total luminance of adjacent view images as shown by solid line in Fig. 3(a), whose luminance decreasing ratio at crossing point is enlarged as only contrast ratios increases.

On the other hand, linear blending technology has a constant total luminance distribution as shown by solid line in Fig. 3(b). In linear blending technology, the luminances of adjacent view images change linearly and complementarily according to the observation position change as shown by broken lines in Fig. 3(b), which leads to 50 % luminances at crossing points. This results in constant total luminance distribution as shown by solid line, which is widely different from the fluctuation in Gaussian distributions as shown in Fig. 3(a).

Thus, total luminance distribution is a key characteristic for judging the linear blending or not.



(a) Gaussian blending in multi-view 3D display



(b) Linear blending in VELF3D display

Fig. 3 Difference of total luminance distribution

2.2 Measurement of Luminance Distribution of VELF 3D Display

Figure 4 shows the measurement system for the luminance distribution. A cooled CMOS camera was used to measure the precise luminance distribution. A pinhole with a diameter of 300 μm was placed 2000 mm away from the VELF3D display. A cylinder prevented light from environment other than from the pinhole. The length of this cylinder was 67.5 mm. The size of the sensor was 11.31 mm × 11.31 mm in length and width. The number of pixels were 3008 × 3008 pixels.

The VELF3D display had 5 viewpoints. On the VELF3D display, the pixels corresponding to each viewpoint were illuminated according to the observation position. The luminance distribution was measured at five positions of shifting 50 mm, 100 mm on the right and the left sides, and center position. The measurement was performed in a dark room. The exposure time of the cooled CMOS camera was 40 seconds. The luminance distribution of one view image was measured 5 times.

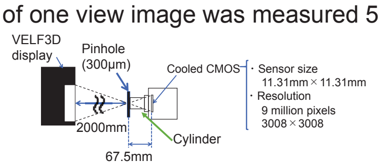


Fig. 4 Measurement of luminance distribution of VELF3D display

2.3 Luminance Distribution of Multi-view Images in VELF3D Display

Figure 5 shows total luminance distributions of the 3 view images at the same measurement position as one in Fig. 6(c). The total luminances remain almost constant at all display positions, although they have some deviations. Especially, luminances at crossing points also have almost the same values as other regions, which is completely different from the total luminance fluctuations in Gaussian distributions as shown in Fig. 3(a).

Thus, this constant total luminance distribution means that linear blending is successfully achieved in VELF3D display.

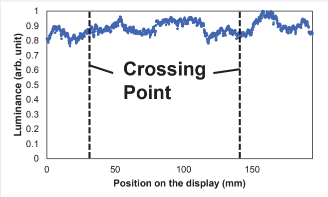


Fig. 5 Total luminance distribution of 3 view images

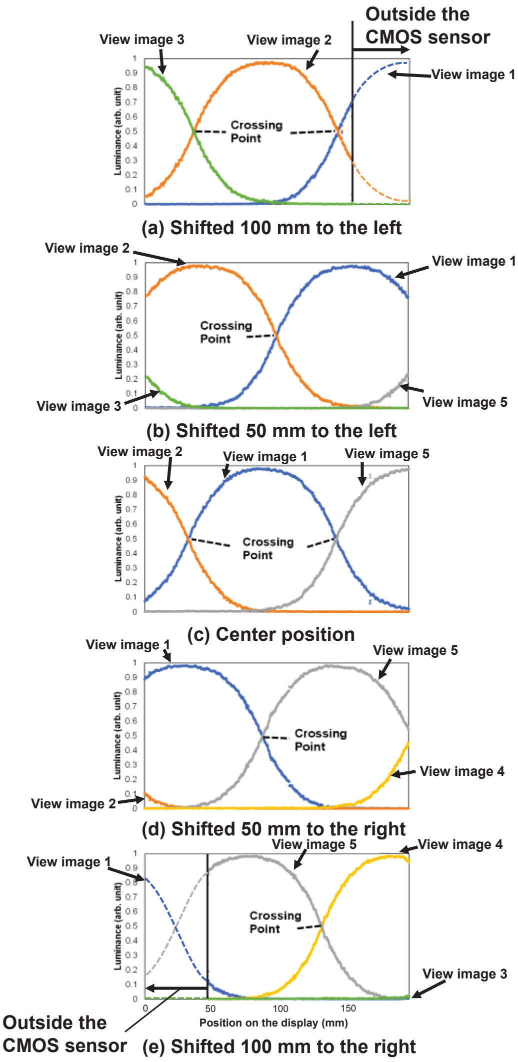


Fig. 6 Luminance distribution measured at 5 observation positions

Figure 6 shows the luminance distributions of adjacent viewpoints of the VELF3D display. The vertical axis of the graph shows the luminance, and the horizontal axis shows the position on the display. These luminance distributions are normalized by the total luminance distributions, for example, as shown in Fig. 5.

All multi-view images have symmetrical shapes and are smoothly switched according to the observation position change because the crossing points of luminance distributions of adjacent viewpoints are at middle display positions of luminance distributions and have almost 50 % luminances, although the curves are rounded because of insufficient resolution in measurement system.

The luminance distributions changes by shifting measuring positions are shown in Fig. 6 from (a) to (e). The same color lines show the luminance distributions of the same multi-view images. In all figures, the luminance distributions of adjacent multi-view images intersect at almost the mid-point of adjacent view-images. In addition, the five multi-view images switch smoothly according to the observation position change.

3 DEPTH PERCEPTION BY MONOCULAR MOTION PARALLAX IN VELF3D DISPLAY

3.1 Evaluation Method for Depth Perception by Monocular Motion Parallax

Figure 7 shows the stimulus displayed on the VELF3D display. Stimulus was three green squares vertically aligned at equal intervals on the display. The square had a side of 19 mm and a vertical spacing of 30 mm on the display. The upper and lower squares were references of the perceived depth, which did not move even when the observation position was changed. The square in the middle was stimulus for estimating perceived depth. Complimentary luminance changes of adjacent view images by linear blending makes the middle square appear to move smoothly when the observation position changes. Designed stimulus depths were 9.8 mm, 19.8 mm, 29.8 mm, 40.0 mm and 50.2 mm on the front side and the rear side of the display, and 0 mm without depth. The distance between the viewpoints of the display used in the experiment is about 2.1 degrees [4]. When the direction of movement of the observation position and the direction of movement of the middle square were the same, the middle square appeared behind the display. In the opposite direction, the middle square appeared in front of the display. The positive depth was in front of the display and vice versa.

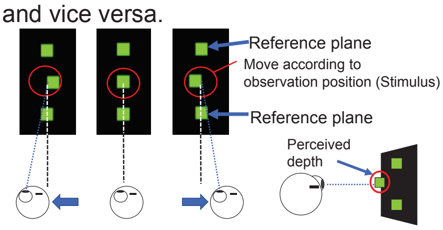


Fig. 7 Stimulus of monocular motion parallax

Figure 8 shows the evaluation method of depth perception by monocular motion parallax. The observation position was 2 m away from the display. For the motion parallax, subjects were let move the head horizontally to the left and right. A slit was placed in front of the observation position so as not to go out of the visual field, and the range of moving the head was limited. The head was moved horizontally to the left and right with a period of 2 seconds in synchronization with the metronome's sound that sounded every second. The perceived depth was measured by using the distance between the thumb and forefinger of the subject. The display was observed with a single eye by covering another eye. The measurement was performed in a dark room.

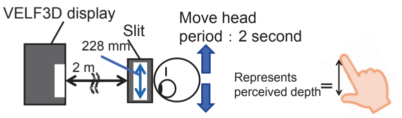


Fig. 8 Evaluation method of depth perception by monocular motion parallax

3.2 Evaluation Results of Depth Perception by Monocular Motion Parallax

Figures 9, 10 and 11 show monocular depth perceptions by monocular motion parallax of three subjects, respectively. The vertical axis of the graph shows the perceived depth, and the horizontal axis shows the designed depth.

All subjects have the same tendency of monocular perceived depths by motion parallax. Monocular perceived depths by monocular motion parallax in VELF3D display have the almost same line as the designed depths at all subjects. Moreover, deviations from the designed line are small.

This appropriate monocular perceived depths as designed depths successfully confirm that VELF3D display can provide the same perceived depth even when observation distance is changed from the viewpoint plane of 1 m to 2 m as shown in Fig. 2.

Thus, appropriate monocular perceived depth can be obtained by smooth motion parallax in VELF3D display.

4 CONCLUSIONS

In this study, we evaluated the luminance distribution of adjacent viewpoints of VELF3D display for confirming linear blending technology and the monocular depth perception by monocular motion parallax in the linear blending technology.

In the luminance distribution, the main characteristics of linear blending are confirmed by the constant total luminance, the smooth change of mixing ratio of adjacent multi-views on the display, and the distribution changes according to the position of the viewpoint. Moreover, in the evaluation of depth perception by monocular motion parallax, the same monocular perceived depths as the designed depths with small deviations can be obtained.

Thus, VELF3D display has linear blending technology and this achieves appropriate monocular perceived depths by smooth motion parallax.

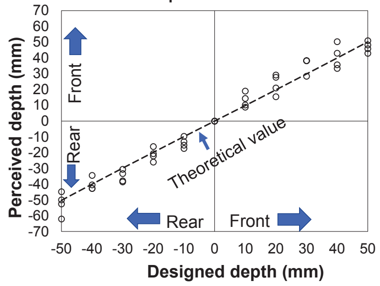


Fig. 9 Depth perception by monocular motion parallax of subject A

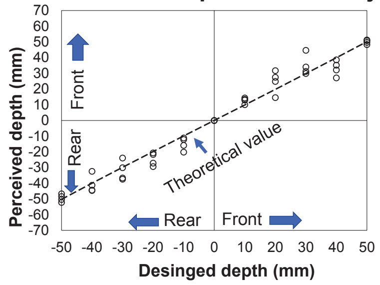


Fig. 10 Depth perception by monocular motion parallax of subject B

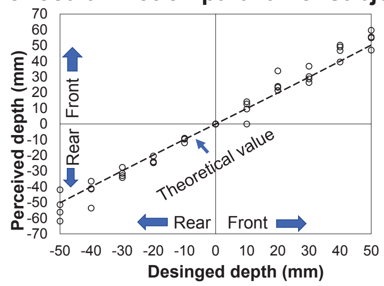


Fig. 11 Depth perception by monocular motion parallax of subject C

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