# Depth Range Control in Visually Equivalent Light Field 3D (VELF3D) Display

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### ABSTRACT

*Light field displays have limited display depth range, which is a serious issue in supporting live action content. Though generating depth maps and re-rendering is a solution, it incurs huge computational cost. In this paper, we achieve depth range compression simply by calculating the weighted average of multi-camera images.*

## 1 INTRODUCTION

Autostereoscopic 3D and light field displays can provide 3D images that offer the feeling of presence without the need to wear 3D glasses or HMD. However, high image quality can be obtained only in a limited depth range around the screen and depth range control of the displayed image is necessary for practical use. Though depth range can be controlled by generating depth maps by calculating and reconstructing 3D images, the calculations are too heavy and complex for practical use. Therefore, we aim to develop a simple depth control method. In this paper, we propose a depth range compression method for VELF3D displays that offer high image quality. It generates viewpoint images by subjecting a small number of images from a camera array to the very light image processing operation of linear blending.

### 1.1 Viewpoint Interpolation Using Linear Blending

We have been studying smooth motion parallax displays using linear blending [1]. As shown in Fig. 1, when the disparity of two neighboring camera images is small enough, i.e. 3-5 arcmins or less, the observer perceives a linearly blended image as a natural intermediate viewpoint image even though it is a doubled image optically. Image weights for blending are in proportion to the nearness of the camera and the viewpoint.

Information processing in human vision is extremely optimized to increase efficiency. Information quantity of the retinal image, which is received by photoreceptors, is reduced by cells in the retina before being transferred to the brain through visual nerves and visual perception is mostly made using lower spatial frequency components. Therefore, there is redundancy in the retinal image. Linear blending utilizes this redundancy. That is, the interpolated image is equivalent to the real viewpoint image for human visual perception. This effect is already known and used in antialiasing image processing and depth fused 3d (DFD) displays.

We have developed autostereoscopic optical linear blending 3D displays using projection optics [2-3] and a ball lens [4]. To eliminate the distortion imposed by projection optics, which seriously degrades images and reduces the linear blending effect, we proposed the flat panel 3D display and confirmed its smooth motion parallax [5-7]; we call it the visually equivalent light field 3D (VELF3D) display.

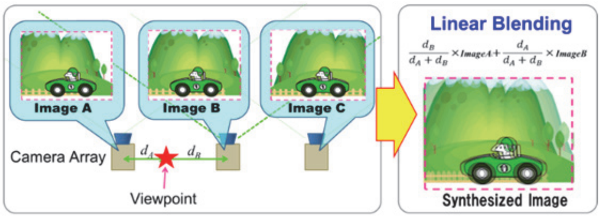



**Figure 1. Intermediate viewpoint image synthesis using linear blending. Visually correct viewpoint image can be generated by weighted averaging the nearest two images, when disparity between the images is small enough.**

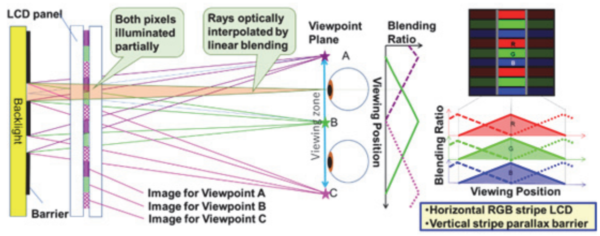



**Figure 2. Structure and mechanism of a VELF3D display.**

### 1.2 VELF3D Display

Figure 2 shows the structure of a VELF3D display. It consists of an LCD panel and a parallax barrier in front of a back light. Though the components of the display are the same as those of parallax barrier type autostereoscopic 3D displays, we blend neighboring viewpoint images aggressively by making aperture width of the barrier and pixel pitch almost equal and using a horizontal RGB stripe LCD panel. Since the variation of blending ratio is linear, linear blending can generate intermediate viewpoint images due to optical interpolation if the disparity between two neighboring viewpoint images is enough small. In other words, interpolated rays can be generated by blending rays for viewpoints. A full parallax display is also possible by using a parallax barrier with special aperture structure [8,9]. Its image quality is high, because interpolation by linear blending enables the use of many pixels for one direction and the reproduction of subpixel edge position through anti-aliasing effects [10]. Live images have been displayed using an array of 5 cameras [11].

## 2 Experiment and Results

In the VELF3D display, only interleaved viewpoint images are sends as the images to the LCD screen. As shown in Fig. 3, in normal shooting condition, the relationships between viewpoints of the display and those of screen are the same or geometrically similar to the camera positions and objects. When the geometrical layouts are the same, displayed image size matches object size.

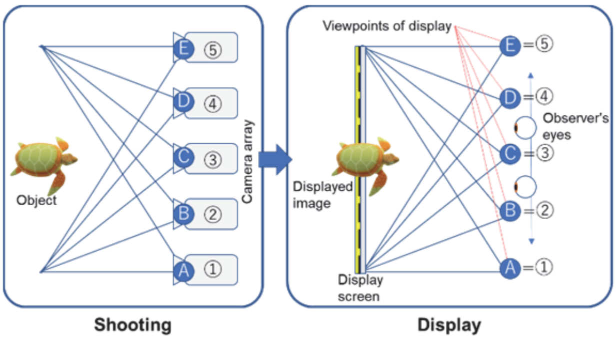



**Figure 3. Normal shooting condition. Relationships between objects and camera positions are the same as those between displayed images and viewpoints of the display.**

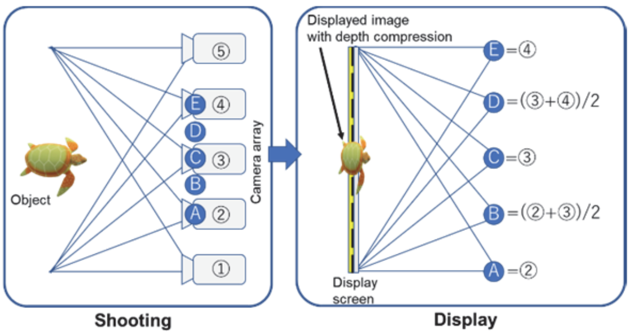



**Figure 4. Depth range compression by reducing disparity of viewpoint image using VELF3D (Method A). Viewpoint images of display Ⓐ-Ⓔ are generated using linear blending of camera images.**

For reducing display depth range, we considered two methods. The first method (Method A), calculates small disparity viewpoint images to display from camera images by reducing the spacing between viewpoints. Figure 4 shows an example of using Method A to produce a half depth range. It generates viewpoints imagesⒶ-Ⓔ from camera images ①-⑤. Viewpoint images Ⓐ, Ⓒ and Ⓔ are central camera images ②, ③ and ④, respectively. Viewpoint images Ⓑ and Ⓓ can be generated by linear blending of the two nearest camera images ②, ③ and ③, ④, respectively.

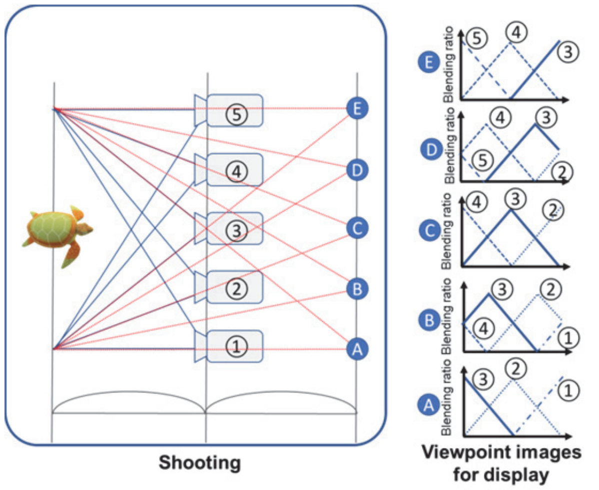



**Figure 5. Depth range compression (1/2) by displaying far viewpoint images using VELF3D (Method B)**

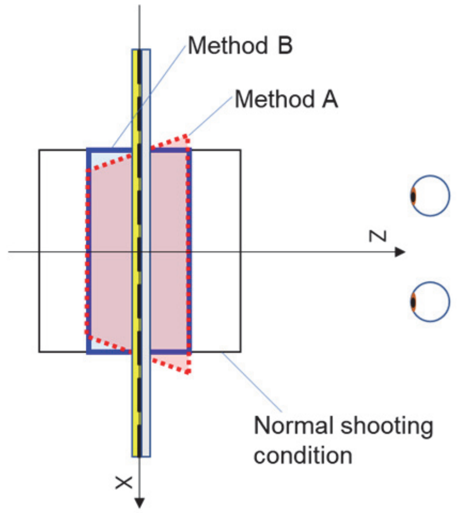
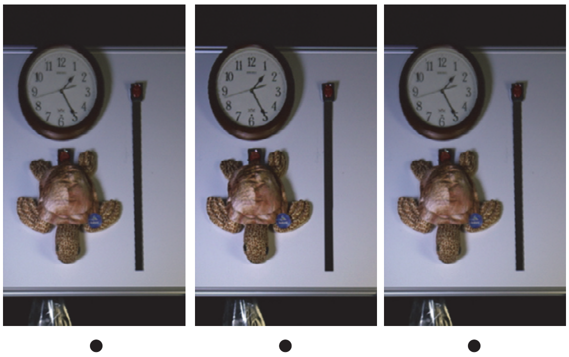



**Figure 6. Image distortions in 3D space induced by depth compression.**

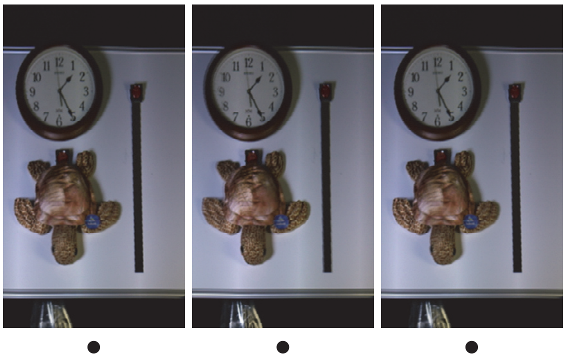
The second method (Method B), calculates far viewpoint images. Figure 5 shows an example of using Method B to attain half depth range. It uses linear blending to generate viewpoint images Ⓐ - Ⓔ from camera images ①-⑤. In this method, the blending ratio varies depending on the horizontal position on the display screen as shown by the graphs.

Though these two methods provide half depth range, blending conditions are different. We compared these two methods in terms of displayed image distortion in 3D space. As shown in Fig. 6, these two methods reduce depth range by half. However, Method A expands object width at the front while that at the rear is compressed. That is, objects are distorted in 3D space. On the other hand, Method B yields natural depth compression without unexpected distortion. Therefore, we choose Method B.

Figure 7 shows images (a) of normal shooting condition at viewpoints ② and ④ and (b) compressed depth images (1/4) using Method B at Ⓑ and Ⓓ. Natural depth compressed images can be achieved.



**(a) Normal condition shooting images**



**(b) Image generated by Method B**

**Figure 7 Original and generated images**

## 3 Discussion

### 3.1 Limitation of Depth Compression

From the viewpoint of application, generated images should not be corrupted by depth compression. We assumed that there was no corruption in the normal shooting condition and discuss the limitation of display viewpoint image generation.

We consider two issues with our method. First one is vignetting induced by a lack of camera images and the second one is the imitation of linear blending.

<u>3.1.1 Vignetting</u>

In the case of Method A, since viewpoints are on the line of the camera array and viewpoint spacing is smaller than that of cameras, no vignetting occurs

In the case of Method B, viewpoints are not on the line of the camera array. Figure 8 shows image generation for higher depth compression (1/3) than that of Fig. 4 (1/2). Viewpoint of image generation is 1.5 times distant in Fig. 8 than in Fig. 4.

For the center viewpoint Ⓒ, though images from three camera are used in Fig. 4, those of five cameras are used in Fig. 8. No vignetting occurs in these two cases. Even if display viewpoint distance becomes infinite, rays became parallel and no vignetting occurs, because in this configuration, the display has smaller width than the camera array.

For the viewpoint at the right end, viewpoint Ⓔ, images from three cameras are used in Fig. 4 and those of four cameras are used in Fig. 8. In these cases, also no vignetting occurs. Even if display viewpoint distance becomes infinite, rays became parallel and no vignetting occurs, as the display has smaller width than the camera array.

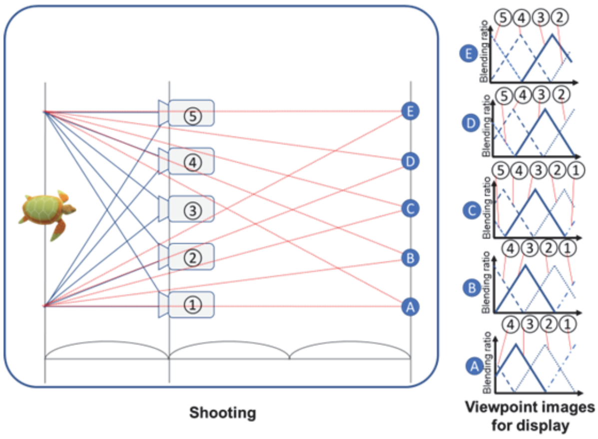



**Figure 8 Depth range compression (1/3) by increasing the disparity of farther viewpoint images (Method B)**

<u>4.1.2 Linear blending</u>

VELF3D display has a limited depth range due to interpolation imposed by linear blending. When the disparity between blended images is large, doubled images are observed. Therefore, disparities between neighboring two viewpoint images must be less than 3-5 arcmins in visual angle.

In the case of Method A, disparities between neighboring viewpoint images are smaller than those of camera images. When the condition of linear blending is satisfied in normal shooting condition, no doubled images are observed with Method A.

In the case of Method B, though blending ratios depend on the position on the screen, disparities of blended images are less than the limit of linear blending, when the linear blending requirement is satisfied in the normal shooting condition. Therefore, visual perception of linearly blended images succeeds, even while viewing distance is kept.

That is, if the disparity is small enough for the normal shooting condition, depth of displayed image can be compressed to any degree. However, if the object has large depth, camera image disparity exceeds the limit of the linear blending condition and the viewpoint image generation fails.

### 3.2 Shooting large depth objects

To shoot large depth objects, there are two approaches. The first one improves viewpoint image generation. For example, if coarse depth information can be obtained, viewpoint images can be generated without failure [12]. However, this incurs increased calculation cost.

The second method increases the number of cameras as shown in Fig. 9. Four cameras are added to the spaces between the original cameras, which are shown in Fig. 3. This approach cuts the disparity in half. Therefore, even if object depth is doubled, no image failure occurs in the normal shooting condition, and any degree of depth compression is possible.

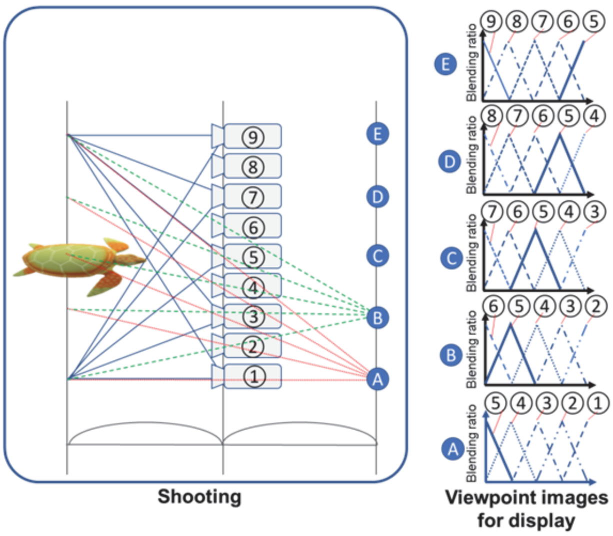



**Figure 9. Depth range compression (1/2) by displaying far viewpoint images using VELF3D for large depth object (Method B)**

## 4

## 5 Conclusions

We have developed a depth range compression method and confirmed its feasibility using a VELF3D display. It incurs only very light image processing cost, as linear blending is based on weighted averaging. When contents are shot without image failure in the normal shooting condition, display depth range can be compressed to any extent without failure.

Since our method doesn't require camera position changes or complex calculations such as depth map generation, it is so fast, exact, and practical that it can be supports live action. Our method is not limited to VELF3D displays. It is applicable to viewpoint image generation for other 3D displays.

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