Scalable Projection-Type Three-Dimensional Display by Using Compensation of Geometric Disotrtion

Youngmin Kim, Sunghee Hong, Sangkyun Kim, Hyunmin Kang, Jisoo Hong, Sangwon Lee, and Hoonjong Kang
Realistic Media Platform Research Center
Korea Electronics Technology Institute
Seoul, Korea
e-mail: rainmaker@keti.re.kr

Abstract— **We proposed an image compensation method of geometric distortion in multi-projection-type three-dimensional display. Projected images from optical modules could be distorted by toed-in configuration of array; we analyzed this relationship by using homography matrix. To verify our method, we designed zigzag configuration of multi-projectors and applied our proposed method. Experimental results will be provided to verify the proposed method.**

Keywords-Three-dimensional display; Geometrical optics

I. INTRODUCTION

Projection-type display has been widely used in three-dimensional display field because it can be spatially multiplexed and is separated from the screen. The most representative projection-type three-dimensional display approach is Holografika, which adopted multiple projectors to provide adequate number of views to the viewers. Holografika used a specially arranged array of optical modules and asymmetrically diffusive screen, where the large angle is Vertical Field of View (FOV) and the horizontal diffusion angle is equal to the angle between the optically neighboring modules and it corresponds to the angular resolution [1]-[4]. However, the projected images from a specially arranged array of optical modules can be distorted as the number of optical modules increase because the optical modules are positioned as toed-in configuration. Each point of the asymmetrically diffusive screen transmits the distorted images into different directions, so three-dimensional image can be deteriorated [5][6].

In this paper, we propose a compensation method of geometrical distortion in projection-type three-dimensional display by using multi-aperture optics. In Section II, we will analyze geometrical distortion due to perspective effects. In Section III, the compensation method will be discussed and practical approach of the compensation method will be described. In Section IV, we will provide simulated results from the compensation method using homography matrix and experimental results.

II. SCALABLE DIRECTIONAL-VIEW DISPLAY BY USING MULTIPLE PROJECTORS

Three-dimensional display technology has been developing since the unprecedented success of the three-dimensional movie ‘AVATAR’. Among the three-dimensional display technologies, holography is the only way to express three-dimensional whole information of objects because the wave-front of object can be reconstructed. However, until now, it is practically hard to develop holography because of massive three-dimensional information contents manipulation and absence of high definition display device. As an alternative, super multi-view display was expounded by enthusiastic researchers. The advantage of the super multi-view display can provide motion parallax as well as binocular disparity because the interval among the views is small enough to provide smooth motion parallax.

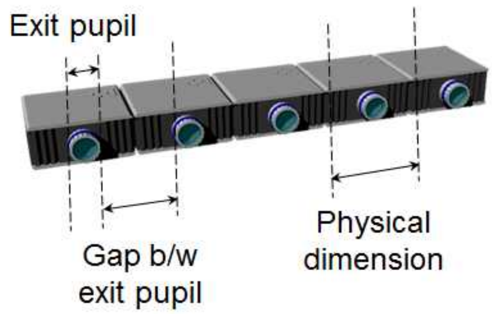

Figure 1. Relationship among the exit pupil, physical dimension, and gap between exit pupils in the array of conventional projection optical modules

Recently, we designed scalable directional-view display technique which is theoretically similar to super multi-view display by using compact and convenient subminiature projectors [5]. The reason why the super multi-view display is easy to be applied practically is effective size of physical projection optical modules. The exit pupil from commercially available projectors is too small compared with physical overall size of projector as shown in Figure 1. When an array of small exit pupil of projection lens is adopted in the super multi-view display, the rearranged three-dimensional rays from asymmetrically diffusive screen present an appearance of a black striped pattern like discontinuous image [6].

To solve this issue, it seems necessary to consider a use of multi-dimensional alignments of projection optics. In the previous paper, we designed zigzag configuration of projection optics by using disassembled commercial projectors for the three-dimensional display as shown in Figure 2. Since the horizontal interval of projection lens of the proposed method is same as the exit pupil of the projection lens, this configuration allows us to provide continuous directional-view images. Furthermore, to enlarge FOV of this configuration, a curved array of projection optics, so-called toed-in configuration, was installed in the proposed method.

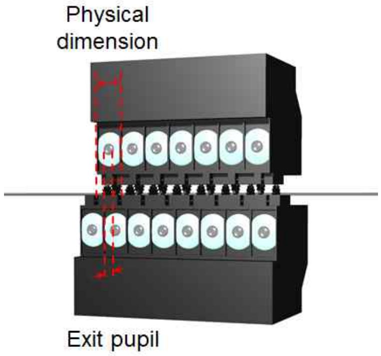

Figure 2. Schematic of proposed method by using an array of disassembled commercial projectors.

III. GEOMETRICAL DISTORTION IN TOED-IN CONFIGURATION

In the toed-in configuration of projection-type three-dimensional display, each projected image can be distorted due to their relative position from the screen. Therefore, it is important to compensate such distortions. In this section, the key issues regarding multiple projectors-asymmetrical diffusive screen calibration will be discussed. As shown in Figure 3, the fixed screen and multi-directional optical modules are adopted in a typical scheme of multiple projection-type three-dimensional display. We assumed that 1) the asymmetrically diffusive screen is flat although this method can be extended to non-planar screens, 2) the projection angle of the images emitted from each optical module is same, and 3) the projectors and the screen can be modeled by perspective transforms.

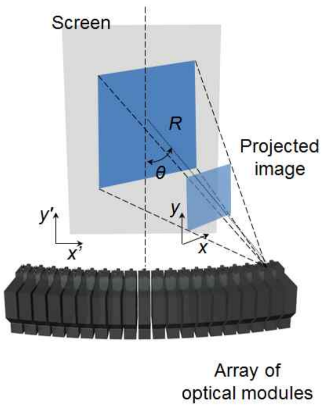

Figure 3. Schematic of the proposed method for the distortion analysis.

Consider a point (x, y) in the projector image plane. This point will be projected to unknown point (x', y') on the screen. Primitive goal in this section is to find out a relationship between two corresponding points. We are able to exploit the fact that all of unknown point (x', y') on the screen, and this can be established by a 3×3 homography matrix between the corresponding points of two different planes. Therefore, it can be expressed by a single projective transform [7],

$$H = \begin{bmatrix} R & 0 & 0 \\ 0 & R\cos\theta & 0 \\ \sin\theta & 0 & R\cos\theta \end{bmatrix} \tag{1}$$

with eight degrees of freedom; R denotes the distance between the center of screen and each projectors, θ indicates the angle between normal vector of the screen plane and projector image plane. The simple example (R = 500 mm, θ = 30º, and the pixel size of the screen plane is 0.2 mm) of above case can be shown in Figure 4.

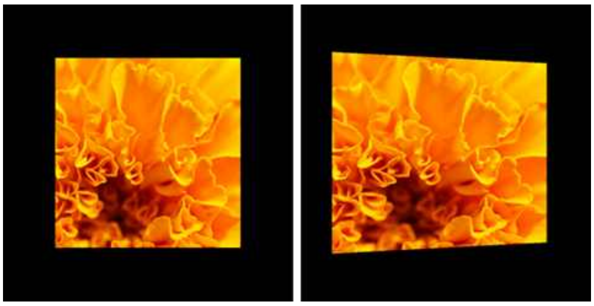

Figure 4. An original image of the projection optical module (left) and distorted image due to the toed-in geometry (right).

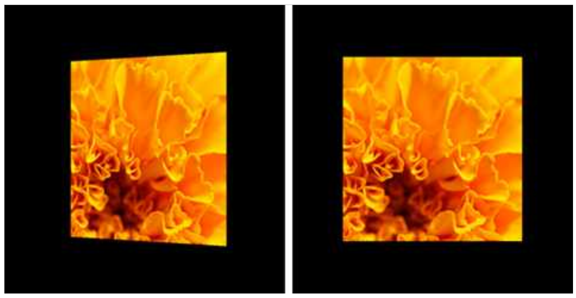

Figure 5. A distorted image from far right position (left) and compensated image by using homography matrix (right).

Since the homography matrix H represents the relationship of geometrical distortion between two coordinates (the projector image plane and the screen plane), the distortion can be compensated by multiplying coordination of original image by inverse matrix of homography. The relationship between pixels of original image and compensated image can be given by

$$(x_p, y_p) = (\frac{R\cos\theta}{R - x_0 \sin\theta} x_0, \frac{R}{R - x_0 \sin\theta} y_0) \quad (2)$$

where (x, y) and (x', y') denote the pixel position of the original image and compensated image, respectively. Using (2), the simulation was performed as shown in Figure 5. We can confirm that the distortion compensation results on the screen are same as original image when the distortion compensation image was projected on the screen.

IV. EXPERIMETNAL RESULTS AND DISCUSSION

To verify our method based on compensation of geometrically distorted images in multi-aperture three-dimensional display, we designed a curved array of multiple projection optical modules with 60º of field of view, which was called as toed-in configuration as well. As a projection optical module, commercially available pico-projectors with the resolution of 1280(H) × 720(V) (native resolution: 640 (H) × 480(V)) were used. This projector does not satisfy the requirement which was mentioned in Section 2, so we disassembled these projectors to provide scalable directional rays. The angular resolution of the toed-in configuration is 0.75º and the exit pupil of the projection optical module was 3.5 mm, as shown in Figure 6. Each projection optical module was connected with single-board computer, which was especially optimized in graphic performance and cost effectiveness.

Figure 6. Experimental setup for verifying our compensation method (up) and enlarged image of toed-in configuration of disassembled projection optical modules (down).

To experimentally verify that the proposed method can successfully compensate directional-view images, we coordinated the parameters of the cameras in the virtual space by using Unity 3D. The field of view of the virtual cameras was set to be same as that of projection optical modules. The captured directional-view images in the system were rearranged for pseudoscopic-orthoscopic conversion. We applied the homography matrix into the rearranged directional-view images for compensation as shown in Figure 7. However, the images still need compensation practically since all projection optical modules are not under the same conditions. So, we compensated this slight difference by using an image capturing device. We set the reference image from center of the optical module, and the projected images from other optical modules were captured. The captured images were compared with reference image from center optical module, and finally we could acquire compensated image in front of the asymmetrically diffusive screen. These findings, therefore, verify the compensation method of the proposed method. Based on the compensated results, we can apply this method for the toed-in configuration. Unlike Holografika method [1][2], this toed-in configuration provides improved FOV because the angle made by toed-in configuration could increase total FOV of the system. Therefore, we could establish distortion-free scalable three-dimensional display by using multi-aperture optics with enhanced FOV.

Figure 7. Experimental results before geometrical compensation (up) and after correction (down).

V. CONCLUSION

In this paper, we proposed compensation method of geometrical distortion in three-dimensional display by using multi-aperture optics. To verify our compensation method, we designed a toed-in configuration of projection optical modules and the contents was acquired by means of computer generated method. Captured directional-view images were compensated by using proposed homography matrix and a detailed compensation was performed by comparing with reference images from center of projection optical module. Further research directed toward real object contents acquisition will be required.

ACKNOWLEDGEMENT

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