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Defragmented image based autostereoscopic 3D displays with dynamic eye tracking

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ABSTRACT

We studied defragmented image based autostereoscopic 3D displays with dynamic eye tracking. Specifically, we examined the impact of parallax barrier (PB) angular orientation on their image quality. The 3D display system required fine adjustment of PB angular orientation with respect to a display panel. This was critical for both image color balancing and minimizing image resolution mismatch between horizontal and vertical directions. For evaluating uniformity of image brightness, we applied optical ray tracing simulations. The simulations took effects of PB orientation misalignment into account. The simulation results were then compared with recorded experimental data. Our optimal simulated system produced significantly enhanced image uniformity at around sweet spots in viewing zones. However this was contradicted by real experimental results. We offer quantitative treatment of illuminance uniformity of view images to estimate misalignment of PB orientation, which could account for brightness non-uniformity observed experimentally.

Our study also shows that slight imperfection in the adjustment of PB orientation due to practical restrictions of adjustment accuracy can induce substantial non-uniformity of view images' brightness. We find that image brightness non-uniformity critically depends on misalignment of PB angular orientation, for example, as slight as $\le 0.01°$ in our system. This reveals that reducing misalignment of PB angular orientation from the order of 10^{-2} to 10^{-3} degrees can greatly improve the brightness uniformity.

1. Introduction

Multi-view autostereoscopic 3D displays (MVA3D) that provide more than two views between viewer's eyes have been of great interest. This is because of their capability to provide binocular parallax to a viewer either at rest or in motion. The latter of which is often referred to as motion parallax [1,2]. However, conventional MVA3D image quality is critically limited due to significant crosstalk [3–7] and brightness non-uniformity [8–10]. Particularly, this non-uniformity of distributions of view image brightness (illuminance), which leads to eye fatigues of viewers with various inter-pupil distances, inherently originates from the presence of a nonzero geometrical gap between a display panel (DP) and a parallax barrier (PB). This is despite the paradoxical fact that the 3D display needs such a gap to generate spatial multiplexing of view images for binocular parallax.

Analyzing illuminance distribution across viewing zones is pivotal for a quantitative estimation of each view's image quality. Fig. 1 shows an example of illuminance distribution of MVA3D view images through a PB at the viewing zone. Point crosstalk depends on illuminance distributions and can be defined for the *i*th view image as follows:

$$\eta_i^N(X)\,(\%) \equiv \frac{\left[\sum_{j=1}^{N} I_j(X)\right] - I_i(X)}{I_i(X)} \times 100, \tag{1}$$

where N is the total number of view images, $I_{i(j)}(X)$ is the illuminance of the $i(j)$th view image (i,j: integers), X is the horizontal position (parallel to a DP) in a viewing zone. As part of 3D image quality evaluation, we adopted the use of a point crosstalk as a function of X rather than the area averaged (integrated) crosstalk. This was because our 3D display concerned 3D image quality at each point over a viewing zone to serve noise-reduced image to a

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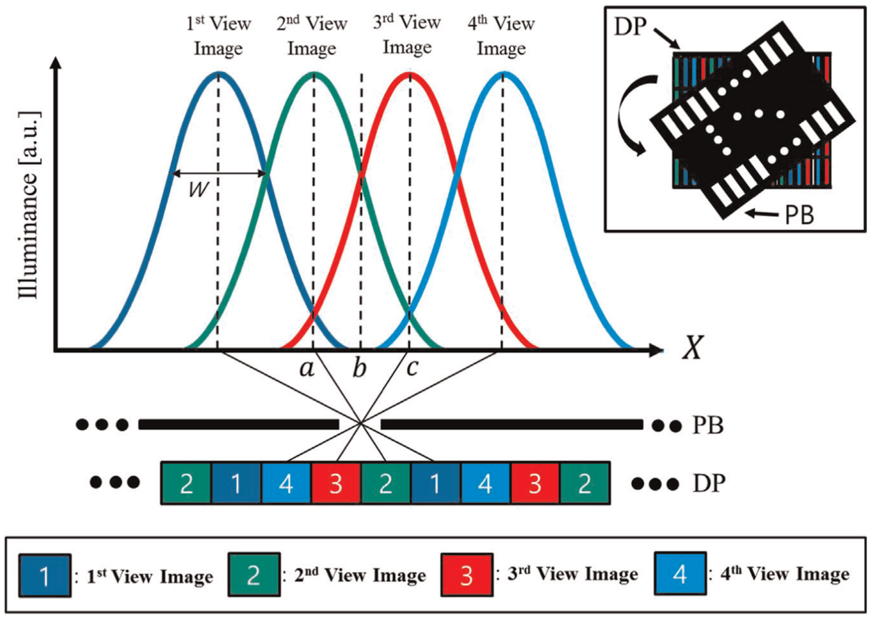

Fig. 1. Simulated distribution of image luminance along the horizontal line of a viewing zone for the 4-view autostereoscopic 3D display with a parallax barrier (PB). DP denotes the display pixels. $\eta_2^4 = 27.6\%$ at a, $\eta_2^4 = 100\%$ at b, $\eta_3^4 = 27.6\%$ at c. The relevant parameters include the optimum viewing distance (OVD) of 600 mm, the view image interval of 16.25 mm at the OVD', the unit pixel width of 59.75 μm, and the slit width of 59.53 μm. The inset represents tilted orientation of a PB with respect to DP.

viewer of various inter-pupil distances and even for cases of instrumental errors in position tracking.

For the 3D display evaluation, we also consider brightness uniformity U_i of the illuminance distribution for the ith view as defined

$$U_i \equiv \left[\frac{\sqrt{<I_i^2(X)> - <I_i(X)>^2}}{<I_i(X)>} \right]^{-1}, \tag{2}$$

where the angle brackets denote averaging over a given horizontal width W at around the sweet spot in the viewing zone. W is the width over which primary illuminance is observed for a given view image as shown in Fig. 1. The parameter U_i for uniformity is defined such that it is inversely proportional to the normalized standard deviation of an illuminance distribution over W. Here the normalized standard deviation refers to the standard deviation divided by the illuminance average taken over the W, to estimate relative uniformity of image brightness, which does not depend on illuminance average. This uniformity is important for the relay of 3D information to viewers of various inter-pupil distances or for a potential 3D service to multiple viewers at a time, considering position tracking errors.

We can expect MVA3D with a PB to produce approximate triangular illuminance distributions of view images at a viewing zone, due to the presence of the gap between a DP and a PB, as mentioned above. However, as seen in Fig. 1, the triangle-shaped distributions then turn into quasi-Gaussian ones as we tilt the PB with respect to a DP (see Fig. 1, inset) to improve image color balance and resolution. We can obtain the quasi-Gaussian distributions as a function of X along a horizontal line of a viewing zone, via simulation of optical ray tracing from display pixels through tilted PB slits to a viewing zone in the 4-view autostereoscopic 3D display with a PB. Illuminance at a given viewing zone could be achieved by integrating all optical rays that landed on it. These distributions exhibit non-uniformity even at the sweet spots of individual view images, as denoted by a and c. Moreover, overlapping features of adjacent view images, cause appreciable amount of point crosstalk that is observed even at the sweet spots. This leads to degraded quality of the 3D images.

Recently, defragmentation of view images of a MVA3D has been reported [11–13]. This 3D display used defragmentation to improve brightness uniformity and reduce point crosstalk. For a moving viewer, dynamic tracking of a viewer's eyes was combined with defragmentation to hold effectively the aforementioned benefits. This technique incorporated defragmentation of a certain number of view images, which was synchronously carried out by display pixel control software that was continuously updated by monitored positions of viewer's eyes. This proposed 3D display could provide multi-views for 3D images, support viewers of various inter-pupil distances, and potentially serve multiple viewers at a time, unlike the Varrier (virtual barrier) based 3D display which employed eye tracking [14]. In addition, the proposed 3D display with defragmentation showed cross-talk level substantially lower than that seen in another type of the 3D display that used a head tracking without defragmentation [6].

However, the measured illuminance distributions of defragmented view images showed their non-uniformity across a viewing zone. This was severe enough to deteriorate view image quality, in contrast to the simulation results. This non-uniformity could take away benefits of uniform brightness of defragmented view images and eventually affected the point crosstalk of the view images.

The brightness non-uniformity may have stemmed from various factors. Firstly, optical refraction through the medium between a PB and a DP could have been a cause. Secondly, it may have been due to imperfect alignment of PB orientation with respect to a DP. (In the 3D display reported in [11–13], the PB orientation was required to balance image color as well as the image resolution between vertical and horizontal directions.) In addition, degraded image quality due to such an imperfect alignment could have been overcome by the method of eye tracking based update of the software for pixel mapping with view numbers. However this would have led to retarded operation of this 3D display at reduced speed.

In this paper, we briefly review defragmentation of view images in MVA3D under dynamic eye tracking and examine the impact of PB orientation on the brightness uniformity of defragmented view images (DFVIs). We simulated optical ray tracing