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Quantitative evaluation for luminance uniformity in 3D displays

Xiaolu Wang [a,c], Hang Fan [a,c], Hongqin Ma [a,c], Shaosen Liang [a,c], Kunyang Li [a,c], Haiyu Chen [a,c], Yangui Zhou [a,c], Jiahui Wang [a,c], Jianying Zhou [a,b,c,*]

[a] State Key Laboratory of Optoelectronic Materials and Technologies, Sun Yat-sen University, Guangzhou, China
[b] SYSU-CMU Shunde International Joint Research Institute, Shunde, China
[c] School of Physics and Engineering, Sun Yat-sen University, Guangzhou, China

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ABSTRACT

An evaluation methodology is proposed to characterize the luminance uniformity in 3D displays. Averaged value and standard deviation are introduced to quantitatively describe luminance uniformity and hence evaluate image qualities of 3D displays. The proposed method was applied to evaluate a commercial 2D/3D switchable autostereoscopic 3D displays, revealing that both the luminance and the corresponding luminance uniformity varied in different observing position. Moreover, the perceived luminance uniformity would diminish in 3D mode comparing to 2D mode.

1. Introduction

These years have witnessed a rapid technological development for three-dimensional (3D) displays, especially the autostereoscopic displays that are free from head-mounted equipment [1]. Comparing to two-dimensional (2D) displays, 3D displays can provide better real world viewing experience. Mainstream approaches for autostereoscopic 3D displays are binocular parallax based (e.g., parallax barrier, lenticular lenses, directional backlights) [2–4]. These techniques create stereopsis by separating left and right parallax images spatially or temporally. Image qualities of 3D displays are mainly affected by the following factors: luminance, crosstalk, resolution, and color gamut [5,6]. Luminance is one of the primary parameters determining the perceived image qualities, as the perceived brightness is the perception of luminance of the screen [7]. Greater background luminance would provide viewers larger depth of focus and better enjoyment [8,9]. However, non-uniform defects existing over the screen causing luminance deviations would decrease image qualities and viewing experience. Thus, maintaining high luminance uniformity is critical for achieving high quality displays.

Luminance non-uniformity existing in 3D displays is generally resulted from the non-uniform defects of LCD panels and, to a large extend, or the imperfect alignment of 3D optical components (e.g., polarizers, lenticular arrays and directional backlight units) causing mura (a kind of non-uniform defect appeared in LCD panels), dead pixels, gap, etc. [10]. Specially, as a result of the directional backlight deployment, the luminance of autostereoscopic is angular dependent [11,12], resulting in the spatial variation of luminance uniformity. However, there has been lacking of the quantitative description, and investigations for the evaluation of perceived luminance in 3D displays appears highly necessary.

* Corresponding author at: State Key Laboratory of Optoelectronic Materials and Technologies, Sun Yat-sen University, Guangzhou, China.
E-mail address: stszjy@mail.sysu.edu.cn (J. Zhou).

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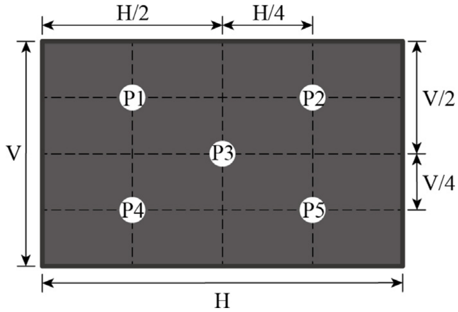

Fig. 1. Example for layout of the position of sampled points ($N = 5$). V and H are the vertical and horizontal width of the screen. The rectangular coordinate system is set with the origin in the center of the screen. P1($-H/4$, $V/4$), P2($H/4$, $V/4$), P3(0, 0), P4($-H/4$, $-V/4$) and P5($H/4$, $-V/4$) denote each test point on the screen, respectively.

Generally, luminance is measured by photometers or CCD cameras [13,14]. Photometers have very limited aperture angle, goniometric system would be necessary when measuring the luminance angular distributions, especially for the autostereososcopic displays of which luminance intensity is very often angular dependent [13]. On the other hand, a CCD camera's spectral response characteristic is inconsistent with spectral luminous efficiency function for human vision. The measurement results of gray levels do not show linear relationship with luminance. Moreover, optical distortions such as vignetting and aberration would appear, diminishing the measurement accuracy [15]. Thus, traditional evaluation method for 2D displays would not be appropriate for 3D displays. Based on a detector of which spectral response is close to human eye sensitivity and well calibrated with illuminance, a photo-detecting system is established herein to simplify the measurement procedures. The luminance distributions could be obtained by illuminance and luminance translation, of which error is relatively small in the experimental condition discussed below.

The proposed perceived luminance uniformity evaluation method was applied to a commercial 2D/3D switchable autostereoscopic 3D displays. In 3D mode, there shows an angular dependent characteristic in both luminance and luminance uniformity. Subjective perception about luminance deviation can be quantitatively described, which gives a reliable parameter for the evaluation of the perceived image qualities of 3D displays objectively. This evaluation method can be widely applicable for all kinds of 3D displays for charactering perceived luminance uniformity.

2. Methodology

2.1. Luminance uniformity

Several spots ($P_1, P_2, \ldots, P_N$) on the screen should be selected on the test points, where N denoting the number of test points which should not be less than 5. To precisely reflect the luminance uniformity of the whole screen, the number of the test points should be as large as possible and the position of test points should be representative, that is, both the pixels in the middle and at the edge of the screen should be taken into account as the sampled area and all of the test points should evenly distribute over the screen. An example layout of the position of sampled points ($N = 5$) is referred to Fig. 1.

At the ith observing position O_i, luminance of the jth test point is L_{ij} ($i = 1, 2, \ldots; j = 1, 2, \ldots, N$). The luminance uniformity could be quantitatively described by the following 3 steps:

(1) Calculate the averaged luminance (A_L) of the test points:

$$A_{Li} = \frac{1}{N}\sum_{j=1}^{N} A_{Li} \tag{1}$$

A_L indicates the background luminance.

(2) Calculate relative luminance deviation of the test points:

$$RD_{Li} = \frac{\sqrt{\frac{1}{N}\sum_{j=1}^{N}(L_{ij} - A_{Li})^2}}{A_{Li}} \tag{2}$$

As human eyes are sensitive to the relative luminance deviation rather than absolute luminance deviation, according to Weber's Law, high level background luminance would diminish human perceptions for the non-uniform defect over the screen [16]. That is to say, the perceived luminance uniformity is increased in high level background luminance. RD_L indicates the luminance difference relative to averaged luminance of the test points revealing the luminance non-uniformity over the screen, which is possible to describe the luminance difference perceived by human eyes. The minimum of RD_L would be 0, implying that luminance discrimination can hardly be distinguished.