

Crosstalk reduction in multi-view autostereoscopic three-dimensional display based on lenticular sheet

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A method to reduce crosstalk in multi-view autostereoscopic three-dimensional (3D) displays based on the lenticular sheet is proposed. Correcting the luminance values of each parallax image displayed on the display screen is employed. We analyze the causes of crosstalk. We deduce the formulas of crosstalk reduction according to the relationship between crosstalk coefficients of each parallax image observed through the lenticular sheet, luminance values of each parallax image displayed on the display screen, and luminance values of each parallax image observed through the lenticular sheet at each viewing position. Experimental results verify the effectiveness of the proposed method.

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Various techniques have been utilized to realize multi-view autostereoscopic three-dimensional (3D) displays. Lenticular display, one of the most promising techniques, is used widely in practical applications. In a lenticular display system, the display screen, which comprises a liquid crystal display, plasma display plate, and so on, is located at the focal plane of the lenticular sheet. The lenticular sheet refracts light from the display screen. Different parallax images displayed through the sheet can be seen at different viewing positions^[1–5]. Since the parallax images observed from the left and right eyes are different, the system can generate stereoscopic information or stereoscopic image display. To avoid moiré fringe and balance resolution degradation of parallax image in both horizontal and vertical directions, the lenticular sheet is always positioned at a certain inclined angle. However, the shape of subpixels on the display screen is rectangular, diamond, and so on. Therefore, lens elements cannot exactly cover the boundaries of the subpixels^[6–8]. This causes parts of subpixels that belong to other views to be cast toward the current view, resulting in considerable crosstalk. Crosstalk influences image quality, hinders proper 3D perception, and lowers visual comfort of the observers^[9–11]. In this letter, a method has been proposed to reduce crosstalk by correcting the luminance values of each parallax image displayed on the screen.

For an n -view autostereoscopic 3D display based on the lenticular sheet, there exists a distribution mode of subpixels for n different parallax images (Fig. 1). Rectangles represent subpixels; numbers 1 to n in each subpixel represent view numbers corresponding to each parallax image; and θ is the angle of slanted lenticular sheet. As shown in Fig. 1, the parallax image observed at the third viewing position consists of subpixels (i.e., between dotted lines) from the third parallax image and some subpixels from the second and fourth parallax images. Therefore, the observed parallax images comprise a crosstalk between neighboring parallax images.

Due to the regular distribution between slanted lenticular

sheet and subpixels on the display screen, each parallax image observed through the lenticular sheet at its view position only receives light originating from the corresponding parallax image and its neighboring parallax images, respectively. We assume that the proportion of received light comes from the corresponding parallax image, its left neighboring parallax image, and its right neighboring parallax image, denoted as c_m , c_l , and c_r , respectively. They satisfy the following relationship

$$c_m + c_l + c_r = 1, \quad (1)$$

where the proportions are defined as crosstalk coefficients.

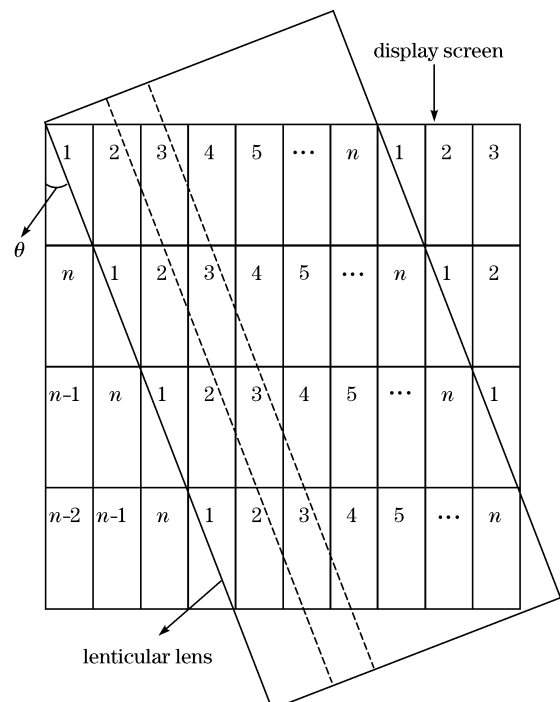


Fig. 1. Distribution mode of the subpixels of each parallax image on the display screen.

At each viewing position, B_m , B_l , and B_r are assumed as normalized luminance of the corresponding parallax image, its left neighboring parallax image, and its right neighboring parallax image, respectively. Then c_m , c_l , and c_r can be calculated as

$$c_m = \frac{B_m}{B_m + B_l + B_r}, \quad (2)$$

$$c_l = \frac{B_l}{B_m + B_l + B_r}, \quad (3)$$

$$c_r = \frac{B_r}{B_m + B_l + B_r}. \quad (4)$$

For an n -view autostereoscopic 3D display based on the lenticular sheet, we assume the luminance of the i th parallax image prepared to display on the screen is B_i ; the luminance of the i th parallax image is B_{bi} ; and the luminance of the i th parallax image observed through the lenticular sheet at the i th viewing position is B'_{bi} , where i is the number from 1 to n . Based on the above analysis, if

$$B_{bi} = B_i, \quad (5)$$

each parallax image observed at its corresponding viewing position exhibits the crosstalk due to the slanted lenticular sheet. Therefore, there is deviation, assumed as δ_{bi} , between B'_{bi} and B_i . Accordingly,

$$\delta_{bi} = |B'_{bi} - B_i|. \quad (6)$$

To reduce the crosstalk, the luminance of the i th parallax image displayed on the screen is corrected to B_{ai} , where i is the number from 1 to n . This satisfies the following relationship:

$$\begin{pmatrix} c_m & c_r & 0 & \cdots & 0 & c_l \\ c_l & c_m & c_r & \cdots & 0 & 0 \\ 0 & c_l & c_m & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ c_r & 0 & 0 & \cdots & c_l & c_m \end{pmatrix} \begin{pmatrix} B_{a1} \\ B_{a2} \\ B_{a3} \\ \vdots \\ B_{an} \end{pmatrix} = \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ \vdots \\ B_n \end{pmatrix}. \quad (7)$$

When viewers observe the i th parallax image displayed on the screen through the lenticular sheet at the i th viewing position, the luminance of the observed image is B'_{ai} . Parameter δ_{ai} is assumed as the deviation between B'_{ai} and B_i ,

$$\delta_{ai} = |B'_{ai} - B_i|. \quad (8)$$

If we can obtain

$$\delta_{ai} \rightarrow 0, \quad (9)$$

then the crosstalk is reduced.

To verify the effectiveness of the theories and methods mentioned above, we performed experiments using two multi-view autostereoscopic 3D displays based on the lenticular sheet. Table 1 shows the parameters of two multi-view autostereoscopic 3D displays based on lenticular sheet used in the experiments. For simplicity, we assume that the light transmittance of lenticular sheet is 100% (i.e., light loss caused by the reflection and absorption of the lenticular sheet is omitted).

Table 1. Parameters of the Two Autostereoscopic 3D Displays Used in the Experiments

Parameters	Experiment 1	Experiment 2
Size of Display Screen (inch)	22	42
n	9	8
Resolution (2D) (pixel)	1680×1050	1920×1080
Resolution (3D) (pixel)	560×350	720×360
Width of Subpixel (mm)	0.0940	0.1614
θ (deg.)	18.44	18.44
Optimal Viewing Distance (mm)	2000	3500

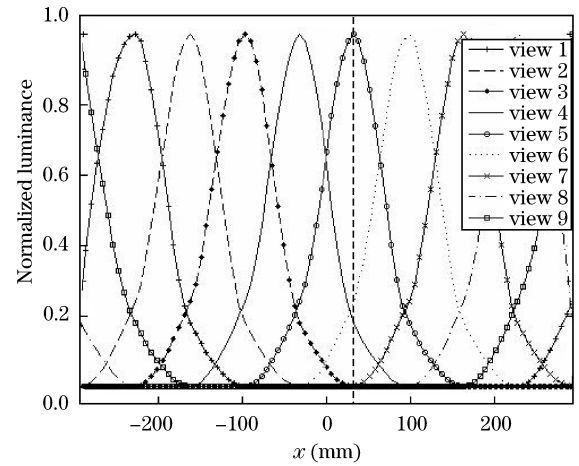


Fig. 2. Normalized luminance of nine-view images along the horizontal direction at optimal viewing distance of 22-inch autostereoscopic 3D display based on lenticular sheet.

Table 2. Luminance Values in Experiment 1 (cd/m²)

i	B_i	B_{bi}	B'_{bi}	δ_{bi}	B_{ai}	B'_{ai}	δ_{ai}
1	125.0	125.0	123.4	1.6	129.0	125.0	0
2	120.0	120.0	121.2	1.2	117.0	120.2	0.2
3	123.0	123.0	121.6	1.4	127.0	123.1	0.1
4	117.0	117.0	119.3	2.3	112.0	116.8	0.2
5	126.0	126.0	124.5	1.5	129.0	126.1	0.1
6	124.0	124.0	123.2	0.8	125.0	123.7	0.3
7	118.0	118.0	120.3	2.3	114.0	118.6	0.6
8	127.0	127.0	124.4	2.6	133.0	127.3	0.3
9	119.0	119.0	121.0	2.0	114.0	119.0	0

In experiment 1, we obtained nine black-white test images by lighting each parallax image in series on the display screen. In black-white test image, only the subpixels corresponding to a certain parallax image are turned on for maximal luminance; all the other subpixels are turned off. We then measured the luminance of each parallax image along horizontal direction x at the optimal viewing distance. Figure 2 shows the normalized luminance of the nine-view images along the horizontal direction at the optimal viewing distance of 22-inch autostereoscopic 3D display based on lenticular sheet. The viewing position corresponds to

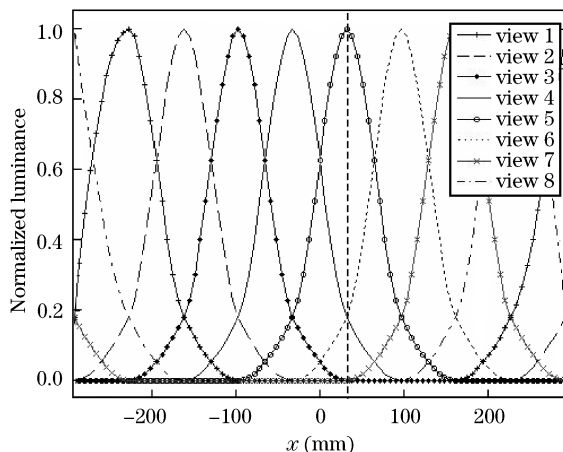


Fig. 3. Normalized luminance of eight-view images along the horizontal direction at optimal viewing distance of 42-inch autostereoscopic 3D display based on lenticular sheet.

Table 3. Luminance Values in Experiment 2 (cd/m²)

i	B_i	B_{bi}	B'_{bi}	δ_{bi}	B_{ai}	B'_{ai}	δ_{ai}
1	141.0	141.0	143.1	2.1	137.0	141.0	0
2	148.0	148.0	146.5	1.5	151.0	148.0	0
3	144.0	144.0	144.9	0.9	142.0	144.1	0.1
4	147.0	147.0	146.3	0.7	149.0	147.3	0.3
5	145.0	145.0	146.1	1.1	143.0	145.2	0.2
6	151.0	151.0	149.2	1.8	155.0	151.4	0.4
7	143.0	143.0	145.0	2.0	139.0	143.0	0
8	150.0	150.0	147.9	2.1	154.0	149.9	0.1

the display center when x is equal to 0, and the vertical coordinate indicates the normalized luminance of the nine parallax images. In Fig. 2, when the normalized luminance of the 5th parallax image is at the maximum (i.e., value of 1), the normalized luminance of the 4th and 6th parallax images are about 0.18 and 0.24 along the direction of the dotted line, from top to bottom, respectively. The values for B_m , B_l , and B_r were 1, 0.18, and 0.24, respectively. Parameters c_m , c_l , and c_r were calculated using Eqs. (2), (3), and (4); their values were 0.70, 0.13, and 0.17, respectively.

Nine different images presenting different luminance values were shown on the display screen. The luminance of each parallax image displayed on the screen was set equal to the luminance of each parallax image prepared, in particular, to satisfy Eq. (5). The corrected luminance values of each parallax image on the display screen were calculated using Eq. (7). The luminance values of each parallax image observed through the lenticular sheet were measured at each viewing position.

The luminance values in experiment 1 are shown in Table 2. As can be seen, δ_{bi} is between 0.8 and 2.6, and δ_{ai} is close to zero, hence the correctness of Eq. (9) is verified.

The same steps mentioned above were employed for experiment 2. Figure 3 shows the normalized luminance of the eight-view images along horizontal direction x at the optimal viewing distance of 42-inch autostereoscopic 3D display based on lenticular sheet. Parameters c_m , c_l , and c_r were calculated, and their corresponding values were 0.74, 0.13, and 0.13, respectively.

The luminance values in experiment 2 are shown in Table 3. As can be seen, δ_{ai} is much smaller than δ_{bi} ; δ_{bi} is between 0.7 and 2.1; and δ_{ai} is close to zero. Same as in the previous, these verify the correctness of Eq. (9).

In conclusion, a method is proposed to reduce crosstalk by correcting the luminance values of each parallax image displayed on screen. We analyze the causes of crosstalk and then deduce the formulas for crosstalk reduction. Experimental results verify the appropriateness of the proposed method. The proposed method is simple, effective, and with low cost. Moreover, it does not change the parameters of the lenticular lens and the structure of the display screen. This method is significant in improving the performances of multi-view autostereoscopic 3D displays based on lenticular sheet.

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References

1. Y.-H. Tao, Q.-H. Wang, J. Gu, W.-X. Zhao, and D.-H. Li, *Opt. Lett.* **34**, 3220 (2009).
2. T. Jarvenpaa and M. Salmimaa, *J. Soc. Inf. Display* **16**, 825 (2008).
3. Q. Wang, Y. Tao, D. Li, and W. Zhao, *Chin. Opt. Lett.* **8**, 22 (2010).
4. X. Wu, W. Liao, and J. Liu, *Chinese J. Lasers (in Chinese)* **36**, 417 (2009).
5. C.-H. Chen, Y.-P. Huang, S.-C. Chuang, C.-L. Wu, H.-P. Shieh, W. Mphöpö, C.-T. Hsieh, and S.-C. Hsu, *Appl. Opt.* **48**, 3446 (2009).
6. L. Zhou, Q. Wang, Y. Tao, D. Li, W. Zhao, and T. Jiao, *Acta Opt. Sin. (in Chinese)* **29**, 3506 (2009).
7. Y.-G. Lee and J. B. Ra, *Opt. Eng.* **45**, 017007 (2006).
8. W.-X. Zhao, Q.-H. Wang, D.-H. Li, and Y.-H. Tao, *Mol. Cryst. Liq. Cryst.* **507**, 67 (2009).
9. P. J. H. Seuntjens, L. M. J. Meesters, and W. A. Ijsselstein, *Displays* **26**, 177 (2005).
10. R. Fukushima, K. Taira, T. Saishu, Y. Momono, M. Kashiwagi, and Y. Hirayama, *Proc. SPIE* **7237**, 72370W (2009).
11. A. Boev, A. Gotchev, and K. Egiazarian, in *Proceedings of 3DTV-CON* 4379396 (2007).