Visual evaluation of 3D image quality by viewer unexperienced in viewing autostereoscopic 3D

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Abstract — Viewing positions of autostereoscopic 3D affect the observed 3D image quality. The response of the people who had little experience in viewing autostereoscopic 3D was investigated. Thirty participants with the normal stereoscopic vision were selected and took the visual evaluation of autostereoscopic 3D at the various viewing positions. Photograph was also taken for the quantitative analysis of the viewing zone characteristics and the uniformity of 3D screen of autostereoscopic 3D. In visual evaluation, the larger difference of good and bad 3D image quality was observed at the viewing distance of 300 cm than at other viewing distance. This result and the periodic trends accorded with the analysis of photos at various camera positions. From these, we found that even the unexperienced viewer can correctly evaluate whether 3D image quality is good or bad.

Keywords *— autostereoscopic 3D, viewing position.*

DOI # 10.1002/jsid.626

1 Introduction

Nowadays, people can experience 3D TV or 3D movies at theater.[1] These 3D applications are based on 3D technologies requiring a special eyeglass. After the commercialization of 3D using the special eyeglass, research on autostereoscopic 3D is under way to remove the discomfort of wearing special eyeglass.[2–10]

In viewing autostereoscopic 3D using lenticular lens or parallax barrier, viewing positions critically affect the image quality of the observed 3D images. People who research and develop autostereoscopic 3D are skilled in evaluating the observed 3D image and finding good viewing positions. Yet the response of the people who have little experience in viewing autostereoscopic 3D is also important for the wider usage of autostereoscopic 3D applications like digital signage.

Various methods for measurement of 3D were reported.[11–15] Some of these included the methods of visual inspection for stereoscopic 3D, but not for autostereoscopic 3D. Hence, investigation of the visual inspection for autostereoscopic 3D needs further research.

In this paper, it was investigated how the general viewers evaluate the 3D image quality of autostereoscopic 3D at the different viewing positions. If the general viewers can identify good and bad 3D image quality at the different positions, they will be able to shift the viewing positions to the better viewing positions. Photograph was also taken at the viewers' positions to quantitatively analyze the viewing zone characteristics and the uniformity of 3D screen of autostereoscopic 3D. Result analyzed from these photographs was compared with the result of visual evaluation.

2 Method

Commercial autostereoscopic 28 view 3D display with the diagonal size of 65 inch and slanted lenticular lens was used as 3D sample.[16] Viewing distances of 200, 250, and 300 cm were selected, in consideration of the product specification of viewing distance of 300 cm. Figure 1(a) illustrated 3D input source of 3D sample for visual evaluation. As 3D input source, 2D + depth map format was used where the left half size represented 2D image and the right half size represented depth map.[17] The spatial distribution of gray level of depth map in Fig. 1(a) determined the depth condition of 2D image of the left side.

To select 30 participants with the normal stereoscopic vision, StereoFly test was used to measure stereo acuity that was determined by the minimum amount of the discriminable depth.[18,19] From StereoFly test, 30 participants who were capable of stereoscopic vision were selected. Stereo acuity of 30 participants were measured to be 56.1 ± 23.8 arc seconds and the average age was 22.9 ± 2.1 years.

Before the start of visual evaluation test, preliminary questions of Table 1 were asked to each participant, to check the previous experience in viewing 3D. Multiple selection was permitted.

Five responses of Table 2 in evaluating the perceived 3D image quality were explained to each participant, using 3D sample and 3D input source of Fig. 1(a). During explanation of less than 1 min, participants were permitted to change positions freely to experience the change of the perceived 3D image quality at the different viewing positions.

Received 08/17/17; accepted 02/07/18.

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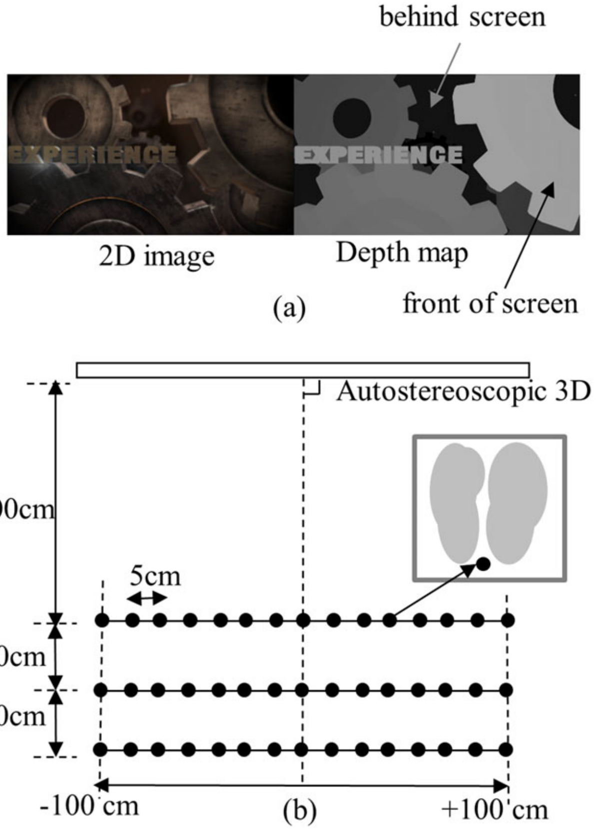


FIGURE 1 — (a) 3D input source with 2D + depth map format. At depth map of right side, bright and dark grays represent the depth in front of and behind the screen, respectively. (b) Setup for the test of visual evaluation at the viewing distances of 200, 250, and 300 cm. Viewing positions were marked on the floor and the center of the ends of two feet of the participants was located at the marked viewing position.

TABLE 1 — List of preliminary questions.

Q1. Did you have experience in viewing 3D?
(a) Yes (b) No
Q2. (Answer if answer of Q1 is yes) What kind of 3D application did you experience?
(a) 3D TV (b) 3D movie theater (c) 3D mobile (d) 3D amusement center (e) others ( )

TABLE 2 — Five responses for visual evaluation of the perceived 3D image quality.

1. Near object looks behind screen. (Pseudoscopy occur)
2. Most of screen does not look sharp.
3. Some area of the screen does not look sharp.
4. Most of screen looks sharp.
5. All of the screen looks very sharp.

Figure 1(b) illustrates the setup for the test of visual evaluation. The ranges of the viewing positions were from −100 to 100 cm with respect to the center of 3D sample. Viewing positions were marked on the floor with interval of 5 cm. At each viewing distances, each participant moved horizontally from the left to the right side by 5 cm. The center of the ends of two feet of each participant was located on the marked positions as the participant changed positions. The center of 3D sample was approximately at the same height as the eyes of the standing participants. At each viewing position, each participant was asked to evaluate the perceived 3D image quality and answer by the response of Table 2. There was no limitation of time in answering the responses. To prevent the dependence on the sequence of the three viewing distances, 30 participants were divided into six groups that the sequences of the viewing distances were evenly distributed as Table 3.

To quantitatively investigate the characteristic of autostereoscopic 3D, 3D image displayed on 3D sample was photographed at the positions similar to the viewing positions of the visual evaluation. Camera was placed on the translation stage and moved horizontally with interval of 1 cm for the range of −30 and 30 cm with respect to the center of 3D sample at the viewing distances of 200, 250, and 300 cm as illustrated in Fig. 2(a). Camera of commercial smartphone (LG G3) was used with the normal setting. Figure 2(b) illustrated 3D input source for photography to investigate the uniformity on 3D screen with respect to the various depth conditions. Nine white bars with equal width were located placed on the black background. And depth conditions from the behind screen to the in front of the screen were determined by gray levels of depth map from 0 to 255 with 32 gray steps.

3 Result and analysis

For Q1 of preliminary questions, all participants answered to have experience in viewing 3D. Figure 3 illustrated the result for Q2 of preliminary questions about the previous experience in viewing 3D. Viewing 3D movie at theater is the largest. 3D applications except 3D mobile were based on the 3D technology with special eyeglass. 3D mobile that one participant had experienced is commercialized 3D smartphone that is based on autostereoscopic 2-view display.[20] This participant had fleeting chance to view 3D mobile but did not possess 3D mobile. The result of the preliminary questions showed that the general people had little chance to experience the autostereoscopic stereoscopic 3D while all of them are familiar with viewing 3D with special eyeglass.

Figure 4 illustrated the average of responses of 30 participants along the horizontal viewing positions for the three kinds of viewing distance. High average value corresponded to the perception of good 3D image, and low average value corresponded to the perception of bad 3D or pseudoscopic image. The difference between the high and low averages was larger at the viewing distance of 300 cm than other viewing distances. Along the horizontal positions, average value at each viewing distance showed the periodic trends. The periods were approximately 21.5 cm for the viewing distances of 200, 26.7 for 250, and 31.5 for 300 cm, respectively.

TABLE 3 — Thirty participants divided into six groups with different sequence of the viewing distances of 200, 250, and 300 cm for visual evaluation.

0	A	B	C	D	E	F
1st	200	200	250	250	300	300
2nd	250	300	300	200	200	250
3rd	300	250	200	300	250	200

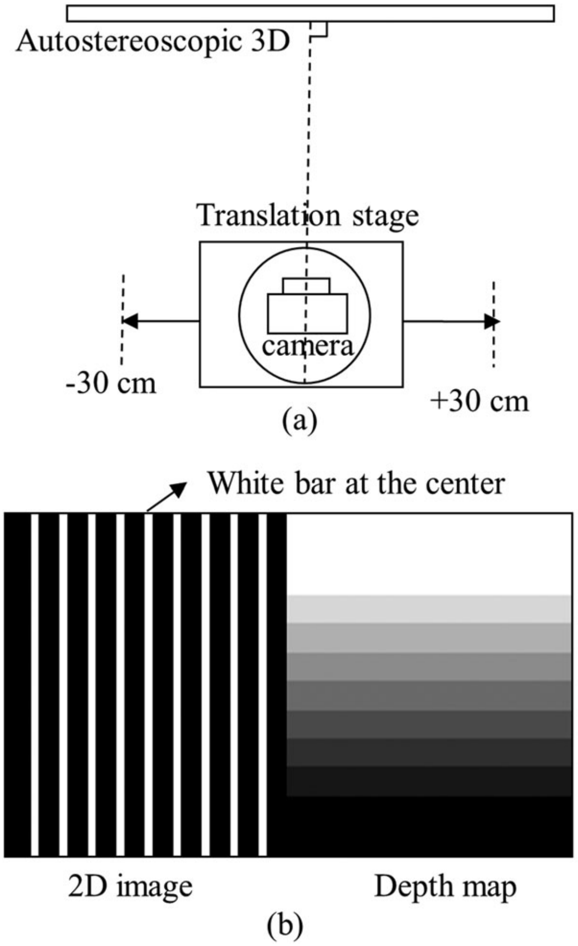


FIGURE 2 — (a) Setup for photography of 3D image at the viewing position. (b) Test image of 2D + depth map format for photography. The gray levels of depth map determine depth conditions of multiple white patterns on the black background. Numbers on the right represent gray of depth map.

There was no limitation of time in answering the responses during the test. Visual evaluation at the first viewing distance generally took about 10 min. As the participant became more familiar to the procedure of the visual evaluation, the time for response gradually became shorter. All of the visual evaluation at three different viewing distances took around 20 min for each participant.

Figure 5 illustrated the average at the viewing distance of 300 cm for groups E&F who first started visual inspection at 300 cm and groups A–D who started visual inspection at 200 or 250 cm. All the participants had little experience in viewing autostereoscopic 3D at the preliminary question. But group of A–D gained some experience during the visual evaluation at viewing distances of 200 and 250 cm and then took the visual evaluation at 300 cm. So groups A–D could be considered to be more experienced compared with group E&F in the visual evaluation at 300 cm. However, there was no noticeable difference between the results of group E&F and A–D in Fig. 5. The result implied that the participants correctly identified good and bad 3D image quality even when they had little experience in viewing autostereoscopic 3D.

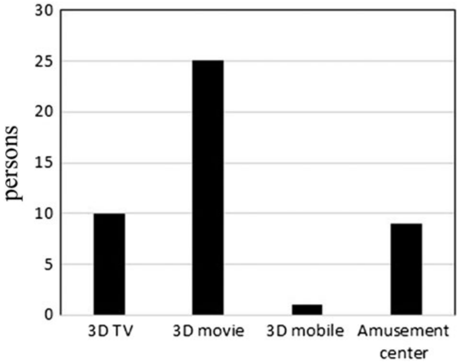


FIGURE 3 — Result of Q2 of preliminary question about the previous experience in viewing 3D. Vertical axis represents numbers of person.

3D screen was photographed at the horizontal range of −30 to 30 cm with the interval of 1 cm, at the viewing distances of 200, 250, and 300 cm using 3D test image of Fig. 2(b). Figure 6(a) showed nine photos at the central section of 3D test image of Fig. 2(b) at the viewing distance of 300 cm. Camera position for photo in Fig. 6(a) was horizontally 4 cm apart. Shapes of white bar in photos at camera positions P_1 and P_9 that are 32 cm apart were similar. At the viewing distance of 300 cm, almost the same photos were repeated with the period of 32 cm. This period was similar to the periodic trends of result of visual evaluation of Fig. 4(a).

Figure 6(b) illustrates the horizontal disparity to induce the depth at the eyes positions of L and R. To induce the depth perception of point F behind screen, F_R seen by the right eye R had to be on right of F_L seen by the left eye L. To induce the depth perception of point N in front of screen, N_R seen by the right eye had to be on left of N_L seen by the left eye. Lower side of photos of Fig. 6(a) represent depth condition behind the screen. In lower parts of photos of P_3~P_7 of Fig. 6(a), white bar at the viewing position of P_m is on the right of P_n for at $m > n$ at the same depth condition. So left and right eye in this range will correctly perceive the white bar behind the screen in accord with the depth condition of 3D input source. In selected sample of autostereoscopic 28 view 3D, movement from viewing zone of view N to view 1 caused the drastic change of the observed image. In Fig. 6(a), this viewing position between viewing zones of view N and view 1 roughly corresponds to P_1 or P_9. If left eye is around the camera position of P_8 or P_9, image seen by right eye will be similar to photo of P_1 or P_2. This will cause the bad 3D image quality or pseudoscopic vision to the participant.

In autostereoscopic 3D, generally best 3D image can be observed at the optimum or designed viewing distance. Figure 7

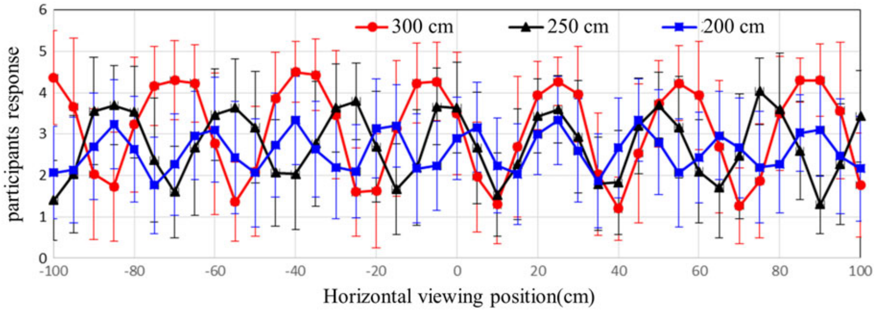


FIGURE 4 — Average of participant responses along the horizontal viewing position. Responses of all participants were averaged at each viewing position. Numbers on the upper right side represented the viewing distance.

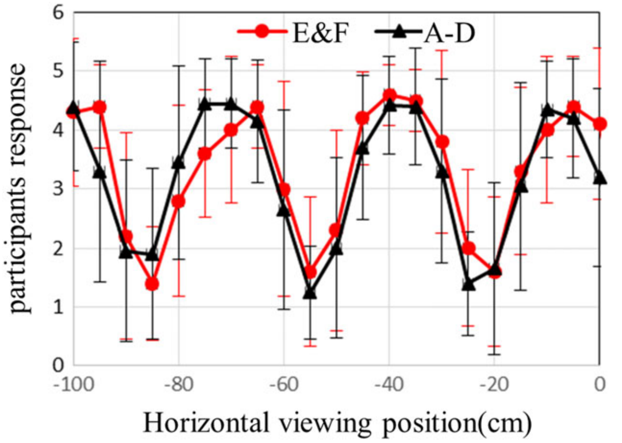


FIGURE 5 — Average at the viewing distance of 300 cm for groups E&F (10 participants) who first started visual inspection at 300 cm and A–D groups (20 participants) who started visual inspection at 200 or 250 cm.

(a) showed photos at the viewing distance of 300 cm. In case of photo at camera position P_3 of Fig. 7(a), shapes of white bars were observed to be uniformly similar at all the active area of 3D screen. And this uniformity was preserved at the photo of the different camera position P_7 though shapes of white bars changed. Figure 7(b) showed photo at the viewing distance of 200 cm. In this photo, shapes of white bars were not uniform at the active area of 3D screen and zone boundary of view N and 1 appeared locally in some part of the photo. This means the disparity to induce the depth perception was not correctly represented at the viewing distance of 200 cm. Photo at the viewing distance of 250 cm also showed non-uniformity at the 3D screen. This non-uniformity related to that the participant saw the different views at these viewing distances. At the viewing distances of 200 and 250 cm, the participant would see some of the 3D screen unclear due to this non-uniformity and this would decrease the occurrences of the responses 1 and 5 of Table 2. Figure 7 accords with the visual evaluation of Fig. 4 that the difference between the highest and lowest averages of responses was larger at the viewing distance of 300 cm. This also accorded with the 3D sample specification of the viewing distance of 300 cm.

Though the whole 3D screen was not uniform at the viewing distances of 200 and 250 cm, white bar at the same position on 3D screen still showed the periodic trends

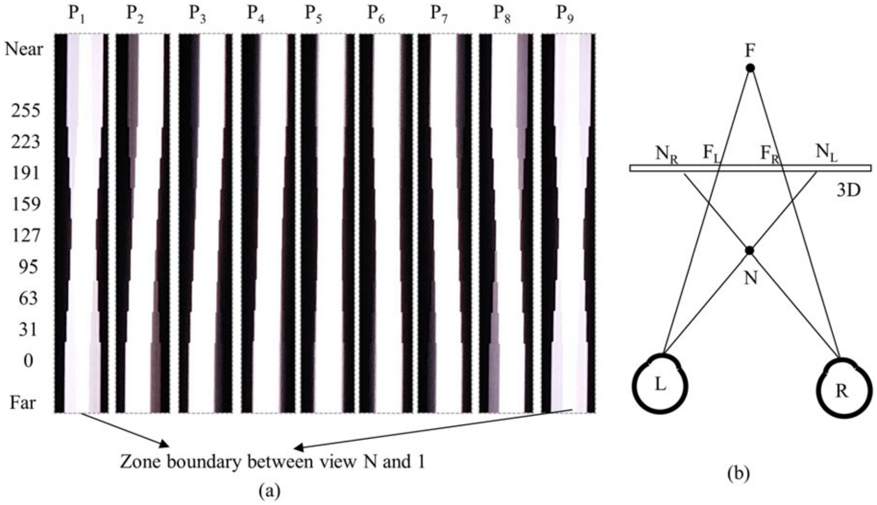


FIGURE 6 — (a) Nine photos of the central section of 3D screen using 3D test image of Figure 2(b) at the viewing distance of 300 cm. P_1~P_9 represent the camera position of each photo. Depth of white bar is different along the vertical direction and the numbers on the left side represent the corresponding gray levels of depth map of 3D input source. (b) Induction of depth perception by horizontal disparity for two eyes at the positions L and R.

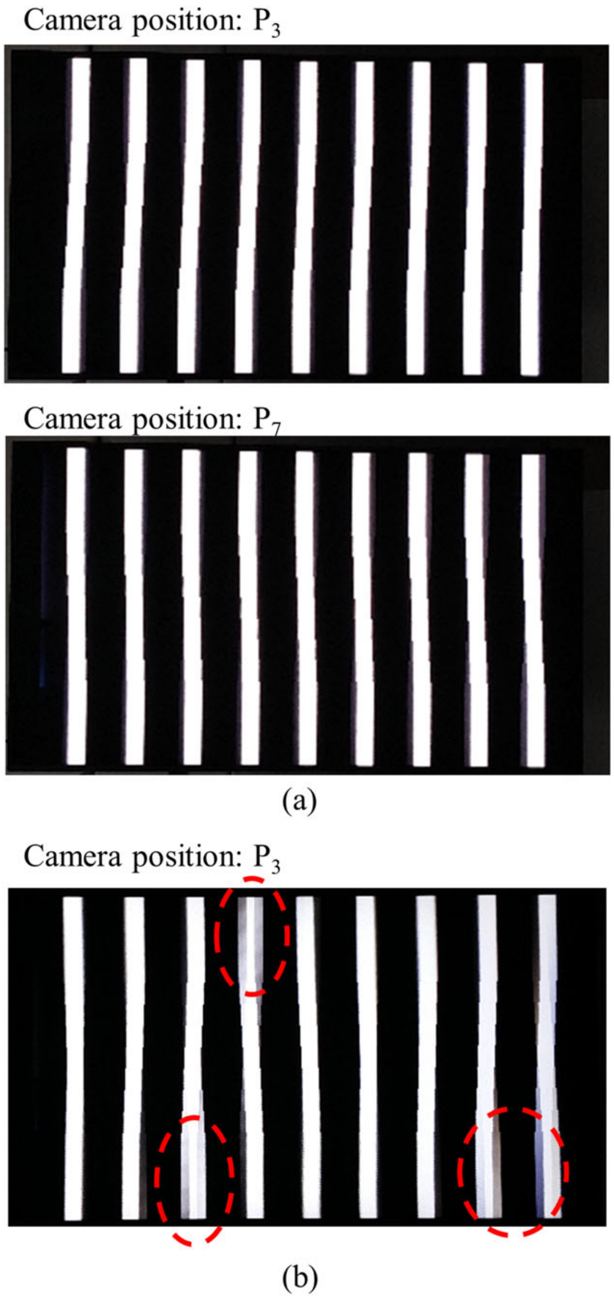


FIGURE 7 — Photo of 3D screen at the viewing distances of (a) 300 cm (b) 200 cm. Dotted circle represents zone boundary between view N and 1 that appeared locally on 3D screen.

horizontally with viewing position interval of 21 and 26 cm, respectively. These periods were similar to the periodic trend of the result of visual evaluation of the Fig. 4.

4 Conclusion

Thirty participants with normal stereo vision were selected who experienced in viewing 3D with special eyeglass but had little experience in viewing autostereoscopic 3D. These participants took the visual evaluation of the perceived 3D image with respect to the viewing positions. To quantitatively analyze the viewing zone characteristics and the uniformity of 3D screen of autostereoscopic 3D, photograph was also taken at the various viewing positions.

Result of visual evaluation showed the larger difference of good and bad 3D image quality at the viewing distance of 300 cm than other viewing distance. This accorded with the 3D sample specification and the analysis from the photos taken at various camera positions. Periodic trends of visual evaluation also matched the repetition of the similar shapes in photos.

From the similarity between the visual evaluation and the analysis of photos, we found that even the unexperienced viewer can correctly evaluate good and bad 3D image quality.

Hence, unexperienced viewers are expected to find good viewing positions in viewing autostereoscopic 3D. It also means the 3D input source of the repeated shapes and different depth such as Fig. 2(b) is effective to understand how the participants saw the 3D image and estimate the good viewing distance and the viewing zone distribution.

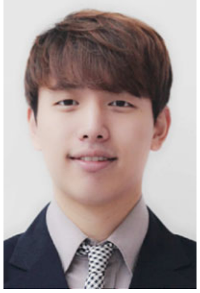
Acknowledgment

This research was supported by the Research Program funded by the Seoul National University of Science and Technology.

References

1 The illustrated 3D movie list, "The illustrated 3D HDTV list," http://www.3dmovielist.com, accessed Feb, 2014.
2 T. Okoshi, Three dimensional images techniques. Academic Press, New York, (1976).
3 C. van Berkel, "Image preparation for 3D-LCD," *Proc. SPIE*, **3639**, 84–91 (1999).
4 B. Javidi and F. Okano, Three-dimensional television, video and display technologies. Springer, New York, (2002).
5 J. Y. Son and B. Javidi, "Three-dimensional imaging method based on multiview images," *J. Disp. Technol.*, **1**, 125–140 (2005).
6 H. K. Hong *et al.*, "Electric-field-driven LC lens for 3-D/2-D autostereoscopic display," *JSID*, **17**, 399–406 (2009).
7 Y. Takaki, "Multi-view 3-D display employing a flat-panel display with slanted pixel arrangement," *JSID*, **18**, 476–482 (2010).
8 J. Kim *et al.*, "Lenticular lens array based on liquid crystal with a polarization-dependent focusing effect for 2D–3D image applications," *J. Inf. Disp.*, **16**, 11–15 (2015).
9 H. K. Hong, "Analysis of the dependence of the viewing zones on the display radius in autostereoscopic 2 view displays of horizontally concave surface," *J. Disp. Technol.*, **12**, 808–814 (2016).
10 M. Salmimaa and T. Järvenpää, "3-D crosstalk and luminance uniformity from angular luminance profiles of multiview autostereoscopic 3-D displays," *JSID*, **16**, 1033–1040 (2008).
11 A. Yuuki *et al.*, "Influence of 3-D cross-talk on qualified viewing spaces in two- and multi-view autostereoscopic displays," *JSID*, **18**, 483–493 (2010).
12 A. Abileah, "3-D displays – technologies and testing methods," *JSID*, **19**, 749–763 (2011).
13 S. M. Jung *et al.*, "New characterization of 3D performance for multi-view autostereoscpic displays," *SID Symp. Dig.*, **43**, 1155–1158 (2012).
14 ICDM (International Committee for Display Metrology), http://www.icdm-sid.org/downloads/idms1.html, accessed Dec, 2016
15 International Electrotechnical Commission "IEC 62629-22-1: 3D display devices – Part 22–1: measuring methods for autostereoscocpic displays-optical, edition 2" (2016)
16 Skymedia 28view "skymedia.com," http://www.skymedia.com, accessed Nov, 2016

17 Dimenco 2D-plus-Depth "https://www.dimenco.eu/downloads/DIM-2DZ-manual.pdf,%E2%80%9D accessed Aug, 2017.
18 Stereo Optical Company Incorporated, USA. Butterfly stereotest. "http://www.stereooptical.com/shop/stereotests/butterfly-stereotest,%E2%80%9D accessed Aug, 2017.
19 H. G. Kang and H. K. Hong, "Comparison of stereoscopic fusional area between people with good and poor stereo acuity," *J. Korean Ophthalmic Opt. Soc.*, **21**, 61–68 (2016).
20 ZTE Axon 7 Max, "https://www.gizmochina.com/2016/10/27/zte-axon-7-max-official-6-inch-display-dual-rear-cam-4gb-ram%E2%80%9D," accessed Aug, 2017.



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