High-visibility 2D/3D LCD with HDDP Arrangement and its Optical Characterization Methods

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Abstract

We have developed a 3.1-inch diagonal 2D/3D LCD with a novel pixel arrangement, called HDDP (Horizontally Double-Density Pixels), for high-quality 3D images. We have improved 3D visibility by broadening the 3D viewing zone where high-quality images can be seen, and we propose optical characterization methods which can evaluate the high-visibility autostereoscopic displays correctly.

1. Introduction

With the improvement in the performance of displays, such as LCDs and PDPs, a variety of 3D displays not requiring special glasses have recently been developed for entertainment, medical, design, and other applications. Although they seem to hold promise for use as next-generation displays, we consider that there are at least two issues that should be resolved.

The first issue is 3D image quality, which is expected to be higher than that of the ordinary 2D displays currently used around us, because sacrificing quality of image will not be accepted by users. In order to improve the 3D image quality, it is effective to use a fully custom-made LCD for autostereoscopic display, because any problems caused by a combination of an LCD and optics, such as lenticular, can be solved. On this point, we have developed a 2D and 3D LCD with a novel pixel arrangement, called HDDP [1] [2] [3]. Both horizontal and vertical resolutions are equal, which results in high 3D image quality. We have also developed a high-quality reflective type [4] and a transflective type of 2D and 3D display [5].

The second issue is 3D viewing zone. The high-quality 3D images should be seen in an expected viewing zone, for example, not only just in front of the display, but also near the front, particularly in mobile terminals for personal use. In other words, 3D images should be seen not only just on the viewing point, but also in the viewing zone. In order to achieve such a wider viewing zone, multi-view or integral imaging may be a good solution. However, these methods need many views, which are not easy for mobile terminals. Therefore, a two-view display is more desirable because 3D contents are easy to prepare. Although a fully custom-made LCD can be applied to any autostereoscopic methods, such as multi-view and integral imaging, we consider it is important to achieve a two-view display with high image quality and high-visibility for personal mobile terminals.

In this paper, we describe a 3.1-inch diagonal 2D and 3D LCD with the HDDP arrangement for ensuring high-quality 3D images, and we also describe improvement of viewing zone by broadening the zone where high-quality 3D images can be seen. In addition, we propose optical characterization methods which can evaluate the high-visibility autostereoscopic displays correctly.

2. HDDP arrangement principle

In a conventional LCD, each pixel (containing three dots: red, green, and blue) is a square. For use in a two-view 3D display, one pixel must be assigned to the left eye and another to the right eye. Each set of left-eye-right-eye pixels, then, will form a rectangle in which the length of the horizontal is twice that of the vertical. This means that horizontal resolution will only be half that of the vertical, which severely limits 3D picture quality. Further, when 2D characters are displayed, this arrangement may result in constituent elements of certain characters being missing, thus causing those characters to be illegible.

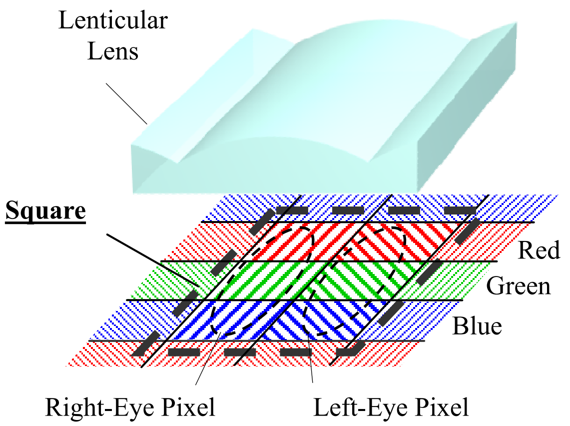

Figure 1. HDDP arrangement

Figure 2. Photo of sample image

Table 1. Display specifications

Display Size	3.1 inch diagonal
Display Area	69.174mm (H) x 38.88mm (V)
Dot Number	427 x 2 (LR) x 240 x 3 (RGB)
Dot Pitch	81μm (H) x 54μm (V)
Pixel Number	427 x 2 (LR) x 240
Pixel Set Number	427 x 240

In response to this situation, we have developed an LCD with the HDDP arrangement which incorporates rectangular pixels whose width is half that of their height. In the HDDP arrangement, the horizontal pixel density is twice that of the vertical. As a result, each left-eye-right-eye set of pixels forms a square, and in a lenticular-lens equipped 3D mode, horizontal resolution will equal that of the vertical, as shown in Figure 1. This not only results in high 3D image quality, it also means that 2D characters can be displayed with perfect legibility without the need for any sort of 2D/3D conversion-structure. That is, left and right pixels can simply be made to display the same content, in which case a full, perfectly proportioned character will be perceived.

Further, horizontal (i.e., left-right) pixel shifting can be conducted in order to make 2D characters appear at varying depths in the overall image. With this design, then, both 3D and 2D images can be displayed simultaneously in the same picture with no need for 2D/3D mode-conversion, and the display structure itself is both thin and uncomplicated.

Table 1 shows the display specifications that we use for the 2D and 3D LCD. Each pixel set consists of 2 pixels (for left and right), and each pixel consists of 3 RGB dots. Figure 2 shows photo of the sample image for 2D/3D LCD, which shows 3D image quality is high.

3. Improvement of visibility

In two-view autostereoscopic displays, the highest impact parameter of 3D visibility is considered to be 3D crosstalk, because 3D crosstalk causes visual discomfort. In general, 3D crosstalk is defined as the leakage of left-eye image to right eye and vice versa, and is calculated as the ratio of luminance profiles. The lower 3D crosstalk value is considered to be preferable. This means that the wider zone of low 3D crosstalk level will be better for high-visibility, and also means that what kinds of 3D crosstalk profile or view profile will be implemented is important.

We classified 3D crosstalk profiles into five levels by the separation of each view, that is, no separation between views in Figure 3(a), slight separation in Figure 3(b), separation with minimum point in Figure 3(c), separation with flat bottom in Figure 3(d) and separation with wider flat bottom in Figure 3(e). In Figure 3(e), the pitch of each view is larger than interpupillary distance (IPD). These figures also show that 3D crosstalk will decrease with increasing the level of separation. If it is desirable that 3D crosstalk is lower, the 3D crosstalk profile in Figure 3(e) is better than that of Figure 3(c).

Figure 4 shows the 3D crosstalk profile of our 2D/3D LCD. This profile has a flat bottom shape and has no clear minimum point. The pitch of each view is 12.5 degrees, which is larger than IPD angles of 9.4 degrees calculated by average IPD of 63mm and design viewing distance of 380mm. Therefore, our 3D crosstalk profile is categorized into Figure 3(e) rather than Figure 3(d). Its wider and flat bottom shape enables the zone to have the good conditions for viewing 3D images, thus bringing about high-visibility. In addition, the 3D crosstalk value of our LCD is about 3.4%, which is sufficiently low for 3D viewing.

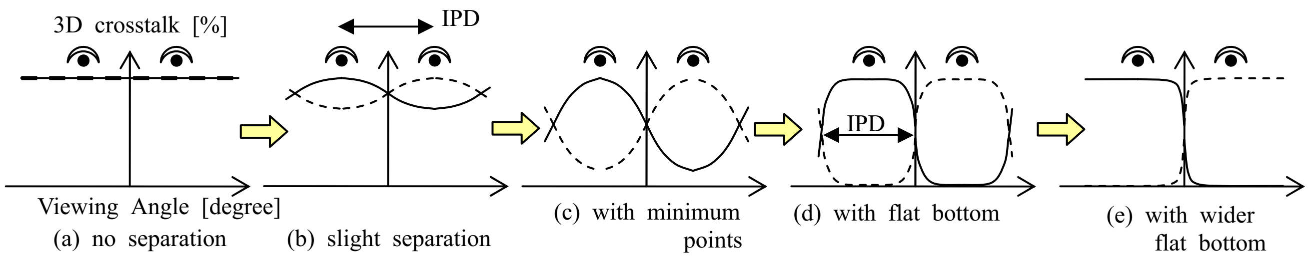

Figure 3. Classification of 3D crosstalk profiles

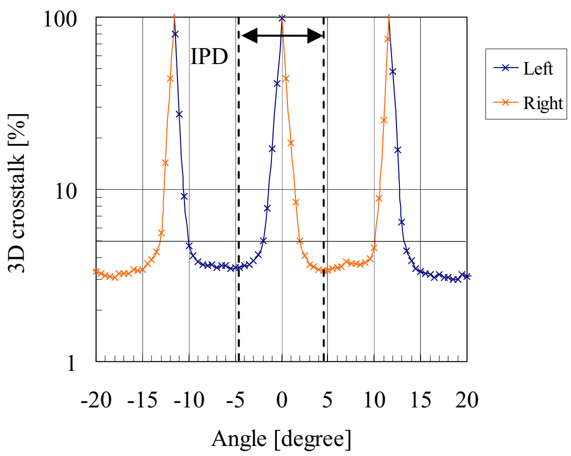

Figure 4. Measurement result of 3D crosstalk profile

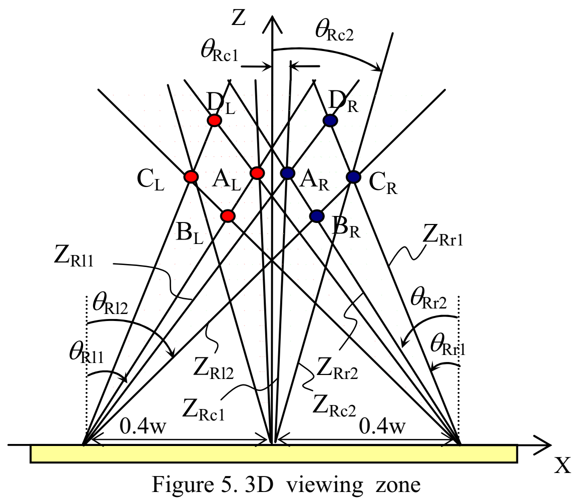

Figure 5. 3D viewing zone

4. Optical characterization methods

Recently, optical characterization methods for autostereoscopic displays have been proposed [6]. These methods require the minimum point of 3D crosstalk profile as the basis for the calculations. For example, the optimum viewing distance is defined as the distance that each eye is located at each minimum point. However, as is mentioned above, the minimum point is not necessarily required for two-view autostereoscopic displays because the minimum point is not essential. Measurement methods should be found on the essence of autostereoscopic displays appropriately, otherwise the methods will limit 3D visibility unreasonably.

In response to this situation, we propose characterization methods which are based on the essence of autostereoscopic displays, and which require no use of 3D crosstalk minimum points. The first essence of two-view autostereoscopic displays is that the zone with 3D crosstalk level under a proper threshold exists. Therefore, first of all, our method is to evaluate the 3D viewing zone not using 3D crosstalk minimum points, but using the proper threshold of 3D crosstalk.

The second point of our characterization method is measurement at three locations, that is, the center, the left and the right of the screen, as shown in Figure 5. We consider the measurement at these three locations in horizontal is essential and effective for certifications of 3D viewing zone.

We consider it is important for autostereoscopic displays to use measurement results at more than two locations, because parallax images can be seen in different angular directions in horizontal, and because it is necessary to measure in which directions the images will be distributed at each location. For this reason, one location measurement is not appropriate for certification of 3D viewing zone, and more than two locations are needed.

The minimal and essential locations are the left and the right of the screen, because horizontal parallax is needed for 3D viewing. In addition, the center of the screen is an important location, because the center is mainly used. Therefore, measurement at three locations is essential. Of course, the more we measure, the more accurate the results we can obtain. However, measurement methods should be minimal and essential. If certification of total screen is required, other means, such as camera test, had better be used together.

The details of the measurement procedure are as follows:
[1] First, luminance profiles of each view are measured at three locations (the center, the left and the right of the screen, which are some of the locations defined in ISO9241-305, "Alternative 9-point location"), and 3D crosstalk profiles are calculated at each location.
[2] Next, the angular ranges under a proper threshold of 3D crosstalk are calculated (i.e., θ_{Rc1}-θ_{Rc2}, θ_{Rr1}-θ_{Rr2}).
[3] Then, by using these angular ranges, each viewing zone for left or right in the shape of a diamond is calculated. For example, the vertex point A_R is calculated as the intersection point of three lines Z_{Rr2}, Z_{Rl1} and Z_{Rc1} as shown in following equations:

$$Z_{Rr2} = (x - 0.4w) / \tan\theta_{Rr2} \quad (1)$$
$$Z_{Rl1} = (x + 0.4w) / \tan\theta_{Rl1} \quad (2)$$
$$Z_{Rc1} = x / \tan\theta_{Rc1} \quad (3)$$

Ideally, these three lines intersect at one point, otherwise the most outside intersection point will be used. If the difference of three points is relatively little, the average point can be used.
[4] Finally, the 3D viewing zone is calculated, for example, which is defined as the zone in which a user with an average IPD can see each image correctly.

The threshold of 3D crosstalk should be determined carefully on human ergonomics data, because the threshold will be affected by many factors, such as luminance, parallax, 3D object size and so on. Of course, it is effective to create several standard levels. At least, the dominant zone of another view should be eliminated.

When 3D crosstalk value itself is required, there are two methods we considered. One method is an average in 3D viewing zone, and another method is a typical value at the specific point that the supplier assigns.

Our characterization methods, of course, can also be applied to 3D crosstalk profile with minimum point. In other words, our methods are upward compatible with the conventional methods.

Figure 6 shows the implementation results when our characterization methods are applied to our 2D/3D LCD. The width of the 3D viewing zone at the design viewing distance of 380mm is about 50mm at 3D crosstalk level of 15%, and about 40mm at 3D crosstalk level of 5%. The minimum viewing distance is 220mm, and the maximum viewing distance is 630mm. These results correspond to actual view of 3D images.

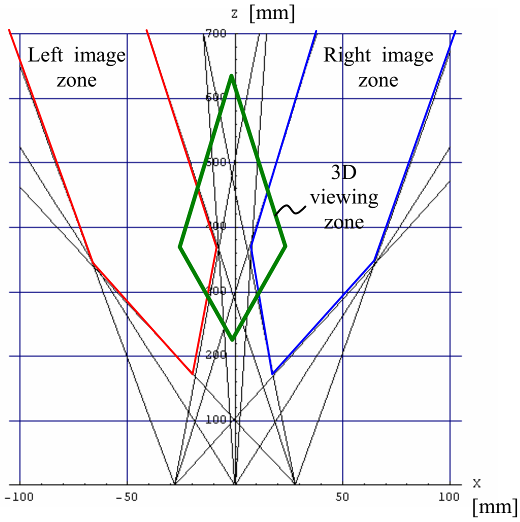

Figure 6. Measurement result of 3D viewing zone

5. Summary

We have developed a 2D and 3D LCD with HDDP arrangement. Its image quality is high, because fully custom-made TFT LCD for autostereoscopic display is used. In addition, its 3D visibility is improved by broadening the 3D viewing zone where high-quality 3D images can be seen. Our proposed optical characterization methods can evaluate autostereoscopic displays correctly, which are based on the essence of autostereoscopic displays.

6. References

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