TESTING METHODS FOR 3D CONTENT VIEWING DEVICES

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ABSTRACT

Nowadays, numerous 3D content viewing devices based on diverse technologies are available on the market. Each device type has a set of parameters that should be checked to avoid a bad viewing experience. We propose a set of techniques to objectively measure the 3D viewing quality and technical characteristics of a device. Special attention is paid to autostereoscopic devices and systems consisting of two projectors. We also present some novel testing techniques for devices with 2D+Z input. Some of the proposed measurement methods are illustrated through actual testing of real devices available on the market.

1. INTRODUCTION

Today's market for 3D content viewing devices has grown significantly owing to an expanding range of available 3D content. Nevertheless, no common objective methods for testing and comparing such devices have yet been developed. Furthermore, not all manufacturers provide full technical specifications and capability descriptions for their devices. Additionally, some medical experts believe that watching low-quality stereo can cause serious injury to the human brain—or at least headaches. These facts make the problem of testing and comparing new devices and of correctly adjusting them very important for both 3D content professionals and 3D cinema viewers.

2. RELATED WORK

Kooi and Toet [1] subjectively examined a large number of typical problems associated with binocular images to determine their influence on observers' viewing experience. They concluded that vertical disparity, crosstalk, and focus mismatch are the most critical factors in determining stereoscopic viewing comfort.

Marc Lambooij et al. [2] discussed specific qualities of human depth perception and described stereo image distortions that can cause visual discomfort. Benzie et al. [3] fully described and classified autostereoscopic, volumetric and holographic displays.

Adi Abileah [4] discussed different types of 3D viewing devices and performed a complete classification

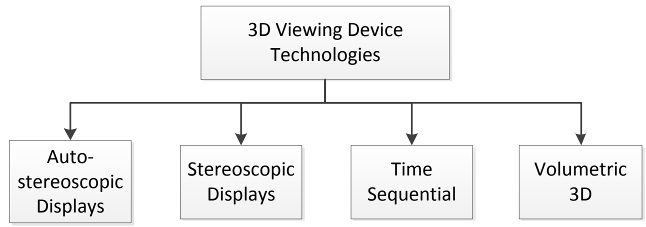


Fig. 1. Technology tree for 3D viewing devices.

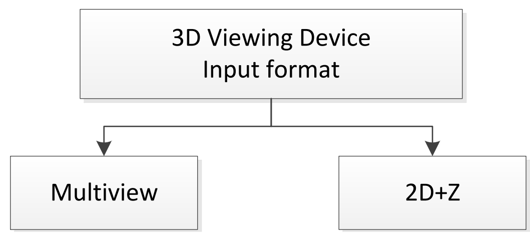


Fig. 2. Classification of 3D viewing devices by input format.

of existing 3D displays. He proposed a set of characteristics that should be measured for each device type, in addition to providing a set of test patterns for the measurement of device characteristics such as view alignment, channel crosstalk and color difference.

Seuntiëns et al. [5] performed subjective testing to determine how different channel crosstalk levels influence human 3D perception. They reported that a crosstalk level of 4% can dramatically spoil the viewing experience, and to maintain viewer comfort, the value of this parameter should not exceed 0.4%. The problem of correctly defining the term *crosstalk* and of identifying the various mechanisms by which crosstalk occurs in stereoscopic displays was discussed in [6].

3. PROPOSED METHOD

Most existing devices for displaying 3D content can be classified according to their viewing technology (see Fig. 1) and the format of their input data (see Fig. 2). Testing methods should be tailored to the particular device technology and input data format.

At this point, we discuss which characteristics should be measured for certain device types according to the

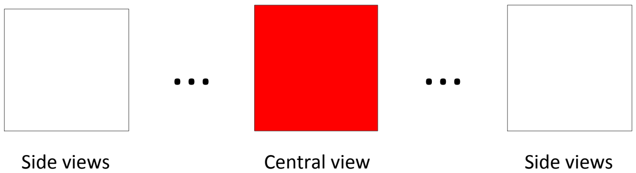


Fig. 3. Test pattern scheme for the optimal distance check.

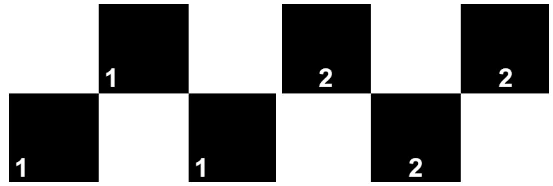


Fig. 4. Chessboard test pattern for the first and the second channel.

technology features used in each device and using the results obtained by Frank L. Kooi et al. [1].

Stereoscopic LCD displays with polarization filters. In this case the most important measurement parameters are channel crosstalk, viewing angle and gamma synchronization (how a given color differs between the left view and right view). Because only one physical LCD matrix is used in such devices, the problem of color mismatch between left and right channels occurs infrequently, but it can be caused by polarization filter corruption in the display or glasses. All of the parameters that are commonly measured for 2D LCD panels should be checked as well, but they are beyond the scope of this paper.

Autostereoscopic displays with lenticular lenses. A crucial point in analyzing such devices is building a map of the area in front of the screen that depicts the optimal viewing areas. This goal can be achieved by separating the area in front of the screen into small blocks; an observer then stands in the center of each block and measures channel crosstalk, the number of visible views, the distance between adjacent views, and the area of the screen covered by one channel. The collected information must then be filtered and interpolated to find the areas of maximum convergence for the measured parameters. These areas correspond to the best viewing positions.

Stereoscopic projector systems with polarization filters. Two independent projectors must be aligned correctly, so the list of parameters that should be checked is large. The most important consideration in this case is correct spatial alignment of the projectors, which is required to avoid vertical disparity. Gamma synchronization, time synchronization (both projectors must show frames with the same identification number at each moment in time), brightness synchronization, focus synchronization and crosstalk level estimation should also be performed. For systems located in a large hall, channel crosstalk should be measured at several locations. The values should then be interpolated to create a map of the best viewing positions in that hall.

Autostereoscopic displays with 2D+Z input. For such devices, a plane image and a depth map serve as input, and view generation occurs inside the device. This fact complicates the measurement of the device's technical characteristics because of the impossibility of directly setting content for each view. But some measurements can still be performed.

Below, we propose test patterns for measuring some device characteristics and describe how these measurements can be performed.

3.1 Crosstalk Level

First, define the observer's current position as the location for which we want to estimate a parameter value. Also, define the main view as the channel that should be seen from the current position in one eye (possibly using eyeglasses if the device requires them to function properly), and define side views as all other views used by the device as input. We define the left (right) eye image as the image that can actually be seen with the corresponding eye (possibly using eyeglasses). Finally, we describe the crosstalk level as the percentage of luminance from the side views that is visible to the observer, or more formally by the following equation.

$$L_{Single\ Eye} = L_{Main} + \alpha L_{Sides} \qquad (1)$$

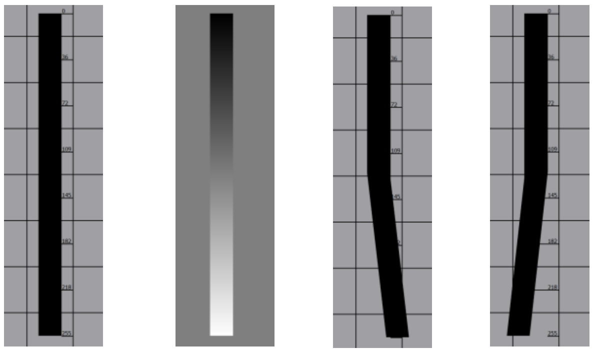
Here, $L_{Single\ Eye}$, L_{Main} and L_{Sides} are the luminances of the single-eye image, main-view image, and side-view image, respectively; α is the crosstalk level between the main view and side views.

To design a convenient method for measuring crosstalk, we select any signal S and set it as the input signal for all side views. For the main view we use the same signal scaled by a factor β. We locate the test image in the main view just below image in the side views. Now the observer must select β to make the image on the main view look identical to that leaked from the side views, as seen from the observer's current position. β will be an estimate of the crosstalk level. To obtain more-accurate measurements, a digital camera records pictures of the screen for different β values; the best match should then be selected. Using this kind of technique, the crosstalk between each input channel and the device's other channels can be measured.

Crosstalk measurement is important for more than just device testing, alignment and comparison; the exact crosstalk value is necessary for the "ghost busting" process described in [7], [8] and [9].

3.2 Maximum View Coverage Distance

As mentioned above, the main point of testing autostereoscopic 3D viewing devices with lenticular lenses is construction of a map that shows the best



(a) 2D input (b) Z input (c) First device view (d) Last device view

Fig. 5. Test pattern for view zone tally (2D+Z input format).

viewing points. The first step of this process is estimation of the distance from the screen for which the main view covers the maximum area. This parameter is important only for devices with lenticular lenses. Theoretically, the observer should see only one view in each eye when looking from the current viewing position. In practice, however, several are visible to each eye. To determine this distance, we use a test pattern having its central channel filled with a red color and all other channels filled with white. The scheme of this test pattern is shown in Fig. 3. Next, we set this test pattern as the input to a device under test; the observer then moves athwart to the screen plane using a fixed step size and takes pictures of the screen with a digital camera. The image with the maximum percentage of red-colored area is selected, and the corresponding distance from the screen is assumed to be the maximum view coverage distance.

3.3 Number of Displayed Views

For devices that accept more than two views as input, the number of views actually displayed can be less than the number received as input (the device may drop some views). For the more distant measurements, we must know the exact number of views being displayed by the device, so we introduce a chessboard test pattern (see Fig. 4). For odd channels, the common chessboard is used; for even channels, an inverted chessboard is used. Finally, the corresponding view number is displayed inside each black cell of each chessboard pattern. To measure the number of views that are actually displayed, the observer moves around the device at the maximum view coverage distance and records all the numbers that he can see. He then tallies the results.

3.4 Number of View Zones and Viewing Angle

At this point we use the same chessboard test pattern that we introduced in the previous section. The observer moves around the device at the maximum view coverage distance and measures the angle between the normal to the screen plane and the position at which the number of views that can be seen simultaneously exceeds some limit (six for the eight-view monitor used in our experiments). Twice this angle is the viewing angle. To obtain the number of view zones, the observer moves around the device inside the viewing angle and counts how many times the central view appears.

3.5 Maximum View Coverage Distance (2D+Z Input)

Using the proposed method, this parameter can be measured only for devices that accept as input not only the source image and its depth but also the background image and its depth. For the input image we use a solid white space. The input depth image is filled with a depth value of zero, and squares with the maximum depth value are drawn on it. Finally, the background image is a solid red color, and the corresponding depth image is filled with a depth value of zero. This input will cause the device to display a completely white image for the central view and images with red stripes for the side views. Next the observer must find the position where the amount of red color visible to one eye is minimized.

3.6 Number of View Zones (2D+Z Input)

To measure this parameter in the case of an autostereoscopic monitor with 2D+Z input, we propose a test pattern with a synthetic depth map (see Fig. 5 a, b) that consists of a wide black stripe in the 2D image and a gradient depth for the stripe in depth map. For the first view generated by the device, the stripe will have a left-to-right direction as Fig. 5 c shows. For the last view, it will have the opposite direction (from right to left as in Fig. 5 d). The observer will thus notice a change of stripe direction when crossing the border between view zones.

3.7 Number of Displayed Views (2D+Z Input)

This test can be done with extremely simple test pattern. The input image is a white area surrounding a narrow vertical red stripe; the corresponding depth map is filled with the maximum value. The observer looks at the screen from a large viewing angle (more than 80 degrees)—this angle will allow him to see all views that are actually displayed. He then tallies the number of visible red stripes.

3.8 Angle Between Neighboring Views

The angle between two neighboring views can be estimated by Eq. (2),

$$\varphi = \frac{\Psi}{vn_{Real}} \qquad (2)$$

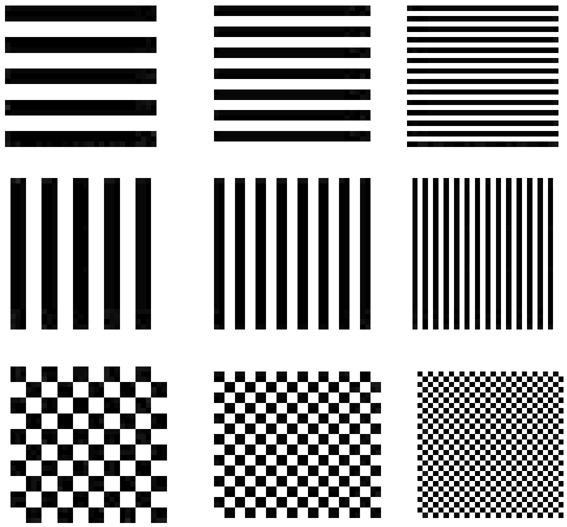


Fig. 6. Actual resolution test pattern.

where Ψ is the viewing angle, v is view zone tally and n_{Real} is the number of views that are actually displayed by the device.

The observer's left and right eyes should see neighboring views (not the same view and not first and fifth views, for example). This condition can be expressed by the following equation,

$$d = \frac{l}{2\tan\frac{\varphi}{2}} \qquad (3)$$

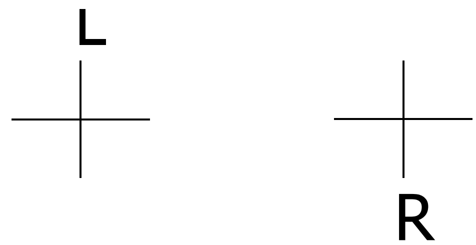
where d is the distance between the viewer and device and l is the average distance between the viewer's eyes (approximately 7 cm).

Using Eq. (3), the optimal viewing distance in terms of distance between the eyes can be estimated. During our experiments, we found that the optimal viewing distance in terms of maximum view coverage and the optimal viewing distance in terms of the distance between the observer's eyes may differ significantly for low-quality devices.

3.9 View Position Quality Map

To estimate the view position quality map, the entire area in front of the screen is divided into small blocks (10 cm × 10 cm in our experiments). Then, a picture of the device displaying the chessboard test pattern (see Fig. 10) is taken from the center of each block. To estimate the quality of a particular viewing position, we use Eq. (4).

$$Q = \begin{cases} 0, & view\ zone\ border \\ n_{Real} - \|V\|, & otherwise \end{cases} \qquad (4)$$



(a) One cell of left channel (b) One cell of right channel

Fig. 7. Alignment test pattern.

Here, Q is a view position quality and $\|V\|$ is the number of different views that can be seen from the current position. A view zone border point is a location from which inconsequential views can be seen. This equation considers invalid (zero-quality) points at the border of the view zones and assumes that the best-quality points are those where only one view can be seen. To build the final map, all values estimated in the previous step are linearly interpolated. An example of such a map is shown in Fig. 9.

3.10 Actual Resolution

To measure this parameter we use a resolution test pattern (see Fig. 6). This pattern is similar to the chessboard test pattern, but instead of numbers, it contains stripes of different widths (from one pixel to three pixels) and directions (vertical and horizontal) inside the white cells. By selecting the narrowest sharply visible stripe, one can determine the device's actual resolution. For example, if all the stripes are sharp, the device resolution is equivalent to the input resolution. The fact that the horizontal stripes with one pixel width aren't displayed correctly, whereas all other stripes are sharp, means the actual horizontal resolution is 50% lower than the input resolution. Also the resolution test pattern can aid in focus synchronization of multi-projector systems (the stripes in all cells should look identical).

3.11 View Alignment

The view alignment check is necessary for stereoscopic projector systems with polarization filters. For this check we propose the alignment test pattern shown in Fig. 7. View disparity can be estimated by measuring the distance between the centers of the crosses.

4. EXPERIMENTAL RESULTS

Several devices have been tested using the techniques described above.

(a) 150 cm distance from the screen

(b) 290 cm distance from the screen

(c) 410 cm distance from the screen

Fig. 8. Experimental estimation of the maximum view coverage distance.

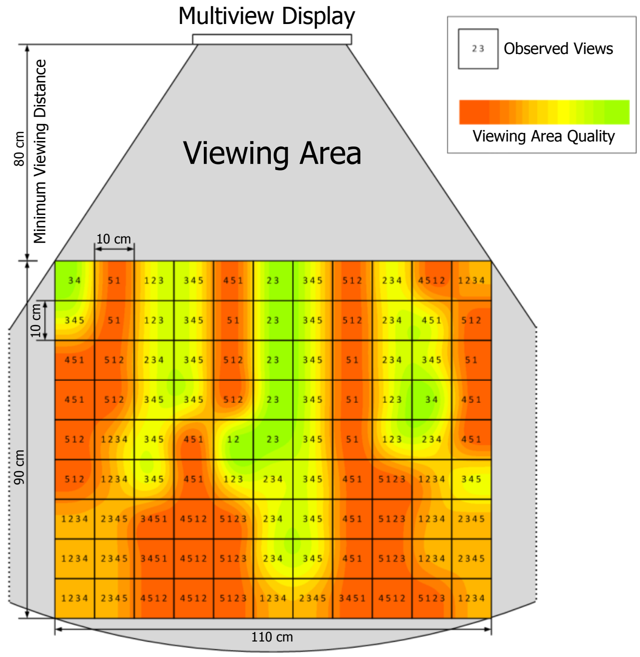


Fig. 9. Example view position quality map.

4.1 Super-D HDL-46

The first tested device was an autostereoscopic lenticular multiview display, the Super-D HDL-46. According to the device documentation, it is a Full HD nine-view display with an optimal viewing distance of about 5 meters. In practice, it was discovered that the device can display only eight views, and its effective resolution is half the advertised value.

Using the screen maximum view coverage test pattern, information about the view zones map was collected. The estimated maximum screen coverage for one view is about 80%—a rate of coverage that was achieved at a distance of 4.1 meters (see Fig. 8). Several characteristics of the view zones map were discovered:

1. The optimal viewing angle is 34 degrees but includes only three view zones. Outside this area, more than six views can be seen simultaneously.
2. The angle between two adjacent views is about 1.5°.
3. On the basis of these results, it was found that optimal viewing distance in terms of distance between the observer's eyes is about 2.9 meters.

Both distances significantly differ from the advertised optimal viewing distance. Information about the "eye-optimal" distance was then added to the view position quality map.

We discovered that the observer can see different views in different areas of the display, but for each area, the observer's left and right eye will see the adjacent views (see Fig. 10). This is why 3D perception of such images is comfortable despite view coverage problems.

4.2 InFocus IN5102

The second tested device was a stereoscopic projector system. This device was examined using the calibration alignment, crosstalk and effective resolution test patterns. The results of our investigation indicate that the final quality of the displayed 3D was increased after calibration.

Fig. 11 shows the stereoscopic system before and after the geometrical calibration process. Using the crosstalk test pattern, the crosstalk level was estimated to be about 4% of the entire signal. This information can be used in the stereo generation or stereo playback step to suppress noise from the main view.

Using a poor resolution leads to a significant quality loss because of inadequate details. For the InFocus system, the effective resolution is 1,024×768, whereas the advertised value is 1,600×1,200. The use of default adjustment considerably reduces the image quality.

5. CONCLUSION

In this paper we have reviewed several widely available devices for viewing 3D content. For these devices, we proposed and discussed procedures for measuring their technical characteristics. Several novel test patterns for autostereoscopic devices with multiview input and 2D+Z input were introduced. Finally, we presented results from

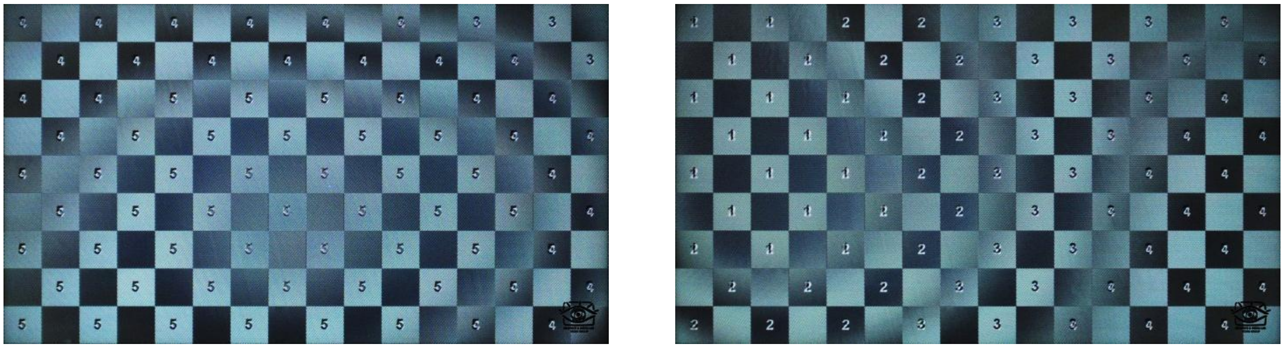
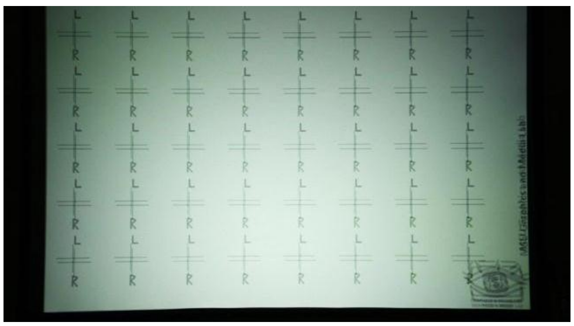
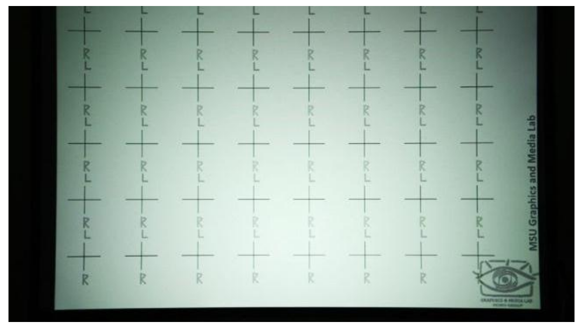


Fig. 10. Chessboard test pattern from different reference points.



(a) Before alignment. Cross centers don't match.



(b) After alignment. Cross centers match.

Fig. 11. Stereosystem alignment.

tests of two 3D viewing devices: the Super-D HDL-46 and InFocus IN5102. This paper introduced a set of test patterns for easy objective measurement of a 3D viewing device's technical characteristics. To expand on our efforts, we intend to create a public database containing the characteristics of devices that are available on the market; data shall be provided by community.

6. ACKNOWLEDGEMENTS

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