Characterization of auto-stereoscopic and polarization based 3D displays: a common approach

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Abstract

Even if auto-stereoscopic and polarization based 3D displays are not working with the same principles, their common aim is to provide two different images in the eyes of the observer. In this paper we show that Fourier optics instrument for viewing angle measurements can be applied to both types of displays. Luminance measurements are made at different locations and what will be seen by an observer in front of the display is predicted. Precise 3D characteristics can be derived and direct comparison becomes possible.

1. Introduction

All 3D displays have the same intrinsic method to provide depth perception: the main idea is always to dispatch two different images in the left and right eye of the observer to provide the depth information. Even if many methods have been proposed to achieve this task, the two most common solutions already available on the market are auto-stereoscopic 3D displays and polarization based 3D displays. Stereoscopic displays require that users wear glasses to ensure left and right views are seen by the correct eye. For polarized based one's the glasses include combinations of polarizers and retarders and a dedicated device is embedded inside the display to polarize differently the two views. On the contrary, auto-stereoscopic 3D displays do not require anything for the observer since different light rays are emitted in different directions to dispatch directly different images in the observer eyes.

Optical characterization of 3D displays is mandatory to optimize their performances and to make efficient comparison between them. Recently we have proposed a characterization method for auto-stereoscopic 3D displays which is based on ultrahigh angular resolution Fourier optics viewing angle measurements and computation in the observer space [1-3]. This method is particularly efficient and provides quantitative parameters for easy comparison of auto-stereoscopic 3D displays with their Qualified Monocular Viewing Space (QMVS) and Qualified Binocular Viewing Space (QBVS), 3D contrast, standard contrast and color shifts, for a complete picture of such display features. The purpose of this paper is to show that the same type of characterization is possible for polarization based stereoscopic 3D displays using Fourier optics viewing angle instrument and dedicated polarization filters. Same type of parameters can be deduced and direct comparison of the performances of the two kinds of displays becomes possible.

2. Experimental

The characterization method is based on viewing angle measurements realized at different locations on the surface of the 3D display (typically center and right and left sides for auto-stereoscopic one's). We use Fourier optics instruments that provide the full viewing angle cone in one measurement rapidly and accurately. Fourier optics aims at converting the angular response of a sample in spatial information that is imaged by a 2D sensor. Each light beam emitted from the sample surface with an angle θ with regards to the normal of the surface is focused on the Fourier plane at the same azimuth and at a position $x = F \tan(\theta)$. The angular emission of the sample is then measured simply and quickly without any mechanical movement. This type of device is available on the market since its introduction by ELDIM in 1993 [4-5].

For auto-stereoscopic 3D displays a dedicated instrument with ultrahigh angular resolution has been developed [1-3]. For polarization based stereoscopic 3D displays a standard viewing angle instrument with additional filters corresponding to the glasses is used. In all the cases, each view of the 3D display is display in white and measured in luminance or in color. Black state is also measured. These measurements are made for all the views of the auto-stereoscopic 3D display and using both left eye filter (GL) and right eye filter (GR) for polarization based stereoscopic 3D displays.

One example of such measurement in the case of 19” commercial polarization based stereoscopic 3D display is reported in figure 1. Viewing angle measurements are realized using left and right eyes filters glasses (GL and GR). Three locations are measured (center, top center, bottom center). In each case and for each filter three measurements are realized: left view ON and right view OFF (Y_{LWRK}), left view OFF and right view ON (Y_{LKRW}) and left and right views OFF (Y_{LKRK}). As shown in figure 1 Y_{LWRK} and Y_{LKRW} present complementary behaviors under the form of limited angular regions. The lobe is probably limited vertically because of the perspective effect due to the location of the retarder film with regards to the crystal cell. Indeed the retarder film is located on the display top surface in this display. The perspective effect due to the thickness of the top glass modulates the polarization of one view along vertical.

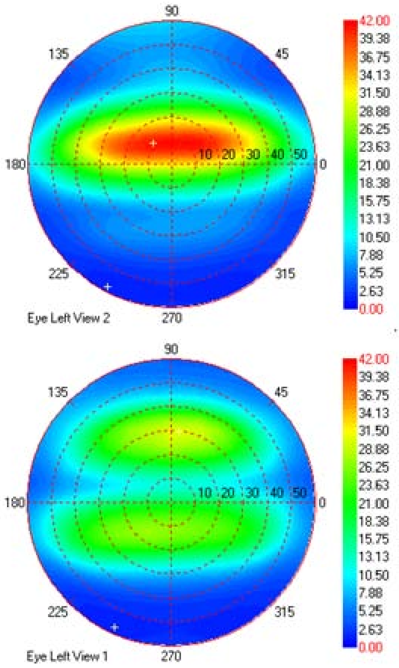

Fig. 1. Y_{LWRK} (top) and Y_{LKRW} (bottom) measured using left eye filter (GL) on commercial polarization based stereoscopic 3D display.

Another example of measurement on a parallax barrier 16” twin view auto-stereoscopic notebook 3D display is reported in figure 2. Here also three locations are measured (center, right center and left center). Y_{LWRK} and Y_{LKRW} show here also complementary results with vertical lobes produced by the barriers.

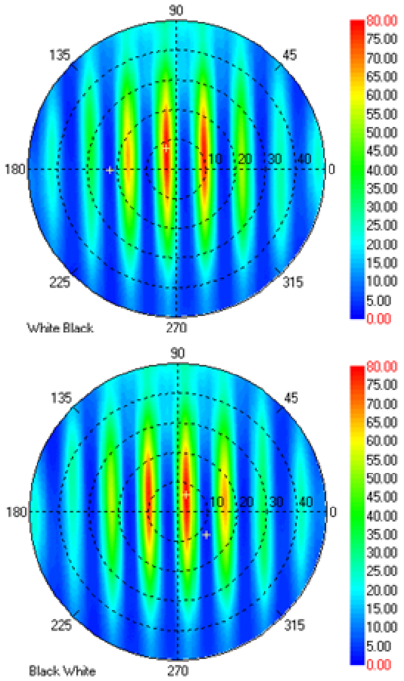

Fig. 2. Y_{LWRK} (top) and Y_{LKRW} (bottom) measured on twin view auto-stereoscopic notebook 3D display.

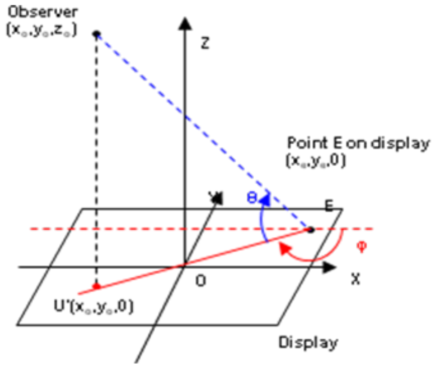

Fig. 3. Definition of the system of coordinates for the observer location.

3. Analysis

Using Fourier optics viewing angle measurement it is possible to calculate the light arriving from this display location to an observer located in front of the display. The observer is defined by its coordinates in the XYZ referential. The origin O is always the display center (cf. figure 3). The X axis, Y axis and Z axis define the transverse, sagittal and coronal planes respectively. The observer position is supposed to be the center of his two eyes. The two eyes are always assumed parallel to the X axis. The inter-pupillar distance is fixed (generally 6.25cm). For each observer position it is easy to calculate the positions of his two eyes in polar coordinates (θ_L, φ_L) and (θ_R, φ_R).

The quality of the 3D display for an observer is directly related to his capacity to display clearly the correct images in his right and left eyes. In case of twin view displays, the two contrasts associated to each eye are first calculated using the following equations:

$$C_L = \frac{Y_{LWRK}(\theta_L,\varphi_L) - Y_{LKRK}(\theta_L,\varphi_L)}{Y_{LKRW}(\theta_L,\varphi_L) - Y_{LKRK}(\theta_L,\varphi_L)} = \frac{1}{\chi_L} \quad (1)$$

$$C_R = \frac{Y_{LKRW}(\theta_R,\varphi_R) - Y_{LKRK}(\theta_R,\varphi_R)}{Y_{LWRK}(\theta_R,\varphi_R) - Y_{LKRK}(\theta_R,\varphi_R)} = \frac{1}{\chi_R} \quad (2)$$

(θ_R, φ_R) and (θ_L, φ_L) are the right and left eye positions in polar coordinates with regards to the measurement location as mentioned previously. The only difference between the two types of displays is that we take measurements realized with GL for C_L and GR for C_R respectively for polarized based displays. The two contrasts are nothing less than the inverse of the 3D crosstalks of right and left eyes χ_R and χ_L as introduced by Montgomery in 2001 [6]. We decided to work with contrasts because there are quantities used every day in the field of standard displays. The 3D quality is optimum only when the two previous contrasts are maximized simultaneously. It is useful to combine the two monocular contrasts into a so called 3D contrast given by:

$$C^{3D} = \sqrt{C_R C_L} \quad (3)$$

A product has been chosen instead of a sum because a good 3D quality requires a good contrast simultaneously for left and right eyes. The square maintains the dimension of the quantity as a contrast which can be compared to the standard contrast of displays. Quantities given by equations (1) to (3) are calculated for a given volume in front of the display and allow definition of QMVS and QBVS. Applied to one location, they ensure that the 3D quality of the display at this location is correct. Nevertheless 3D quality must be maintained on the entire display surface. Multi-location analysis is helpful in this sense. C_L, C_R and C_{3D} are calculated separately for each location and the minimum value obtained for each observer position is used to define QMVS and QBVS. When the measurement locations are cleverly selected an overall evaluation of the display can be done.

4. Some results

Using angular contrasts given by equations (1) and (2) left, right and 3D contrasts have been calculated for the polarization based stereoscopic 3D display using three measurement locations in a box of 600x600x1200mm in front of the display. All these diagrams show sharp emissive horizontal bands at an angle around 9°. The maximum of contrast is around 5 for right eye and 4 for left eye. These values are very low compared to those generally measured on auto-stereoscopic 3D displays (10 to 90 are commonly computed on auto-stereoscopic 3D displays). It is nevertheless in agreement with what is reported in the literature [7]. 3D contrast shows a lower value of only 3.2 at maximum (cf. figure 4). We can define a QBVS by selecting a boundary value for 3D contrast (for example 2.5 in figure 4.b).

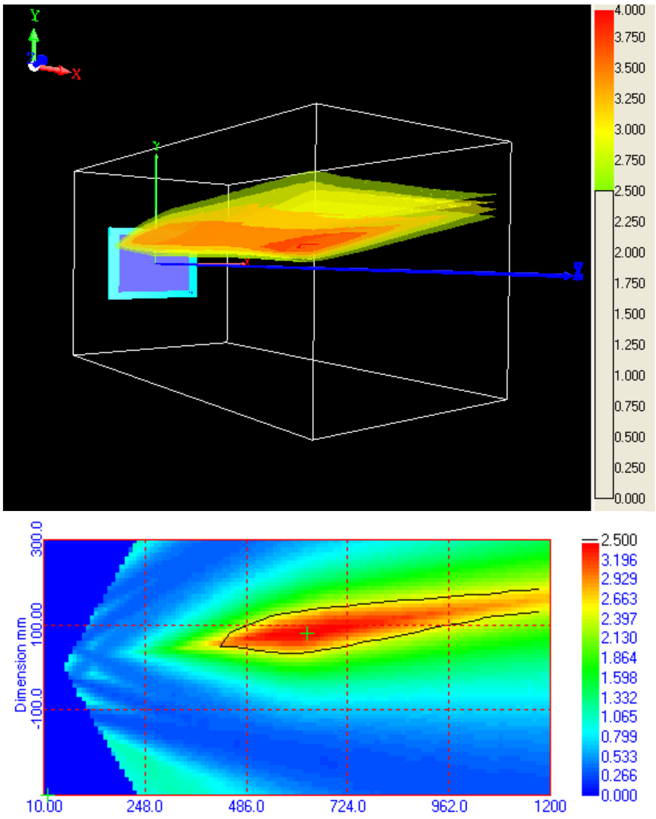

Fig. 4. 3D contrast calculated using three locations in a box of 600x600x1200mm for the polarization based stereoscopic 3D display: volume (top) and sagittal plane (bottom).

Same type of analysis has been realized for the auto-stereoscopic notebook 3D display. Even if the working distance is little shorter than for the other display we have calculated in the same box volume for direct comparison. Corresponding 3D contrast is reported in figure 5. The maximum values are much higher (around 19 in this case) than for the polarized based 3D display but the QBVS is also much reduced. Here only two very thin vertical bands are available for correct viewing in 3D.

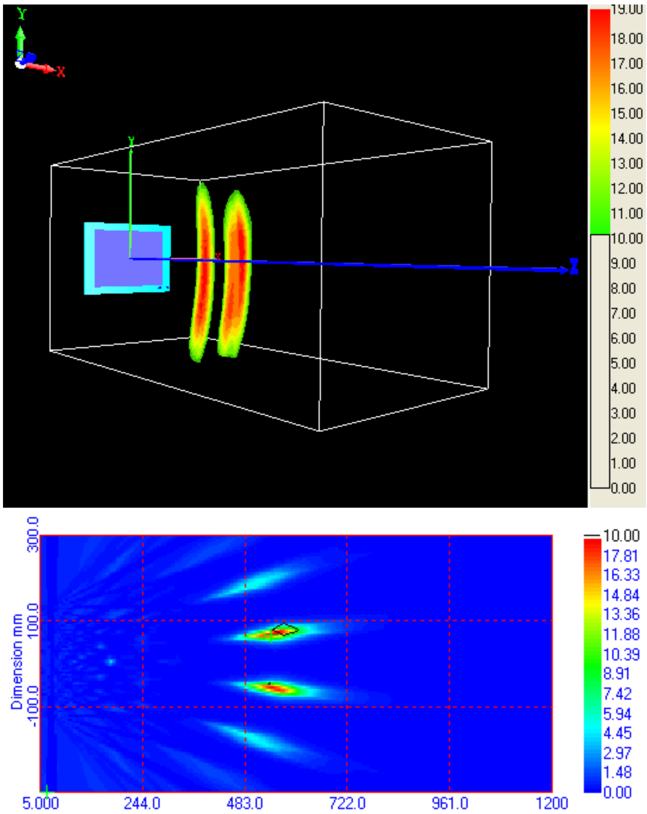

Fig. 5. 3D contrast calculated using three locations in a box of 600x600x1200mm for the auto-stereoscopic 3D display: volume (top) and transversal plane (bottom).

Then it is quite easy to evaluate different parameters related to these volumes (viewing freedom along the three directions, volume, and color shift inside the volume…). Standard contrast values averaging on the two eyes can be also calculated to verify that the standard contrast is sufficient in the volume where the 3D contrast is optimized.

5. Summary

In this paper we have shown that the same type of method can be applied to characterize polarization based stereoscopic 3D displays and auto-stereoscopic 3D displays. We use Fourier optics viewing angle measurements at different locations on the surface of the display to predict what will be the contrast in the eyes of an observer located in front of the display. For auto-stereoscopic 3D displays a very high angular resolution is needed an so dedicate ELDIM VCMaster3D system is used. For stereoscopic displays, standard viewing angle system with additional glass filters is used. From the calculations, Qualified Monocular and Binocular Viewing Spaces (QMVS and QBVS) can be deduced. In the paper we have applied the method to one commercial polarized based 3D display and one auto-stereoscopic notebook 3D display. Even if the applications covered by the two displays are not similar, direct comparison of the two technologies using the same physical parameters become possible. On the examples analyzed in the paper we have seen that a much better 3D contrast is obtained for the auto-stereoscopic but the QVS are much reduced than for the stereoscopic display. This latter display suffers from a very low 3D contrast (only about 3) but which is sufficient in practice to get quite good depth sensitivity.

6. References

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