11.2: *Distinguished Paper:* VCMaster3D: A New Fourier Optics Viewing Angle Instrument for Characterization of Autostereoscopic 3D Displays.

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Abstract

We introduce a new way to characterize auto-stereoscopic 3D displays using multi-location viewing angle measurements and calculation of 3D properties in the observer space. We show that a measurement with a very high angular resolution and low parasitic light is needed. A new Fourier optics instrument dedicated to this application is introduced that exhibits a practical angular resolution better than 0.03° for an aperture angle of 50° and a very low level of parasitic light. The specific problem of geometric compensation of 3D displays is examined using multi-locations measurements from different displays.

1. Introduction

Optical characterization of auto-stereoscopic 3D displays is mandatory to optimize their performances and to make efficient comparison between them. Up to now, quite simple optical characterizations can be found in the literature where a single detector moves horizontally at the optimal viewing distance [1]. More sophisticated techniques like goniometers or Fourier optics instruments have also been used but generally in a quite restricted way analyzing only one single cross section in the observer space [2-5]. From these limited information, different parameters have been defined such as 3D crosstalk, optimum viewing distance, viewing freedom that give a first evaluation of the performances of a twin view 3D display [4]. The situation of multi-view displays is much complex even if the measurement procedures are very similar. In particular, since three or more views can be contributing to the image seen by one eye, the perceived image quality via distribution of crosstalks becomes difficult to analyze even if different attempts have already been made in this sense [5]. Recently we have proposed a method based on ultrahigh angular resolution Fourier optics measurement and computation in the observer space [6-7]. In the following we give some more details in particular concerning the opportunity to measure different locations on the display surface.

2. Experimental details

2.1. Requirements for angular resolution

The angular resolution of a viewing angle measurement plays a key role in 3D display characterization when the light arriving in the eyes of an observer in front of auto-stereoscopic display needs to be predicted precisely (cf. figure 1). It defines the capacity to distinguish between two different light beams coming from the same location but with very close directions. To be realistic the accuracy of the calculation in the observer plane must be near the one provided by the human eye pupil diameter (1 to 4mm). On axis, the maximum position uncertainty Δx can be expressed versus the angular resolution Δθ as follows: $\Delta x = D \tan \Delta\theta$. The need of angular accuracy increases with the observer distance and becomes extremely demanding for large size 3D TV (cf. figure 2). The angular resolution of 2° that is usually found in goniometers, is not sufficient even for small displays. Even the 0.5° angular resolution obtained with conventional Fourier optics viewing angle systems is not sufficient except for very short working distance. For these reasons, ELDIM has developed a new Fourier optics instrument with ultra-high angular resolution. Our target was 0.03° to cover all displays sizes and especially 3D Television (cf. figure 2).

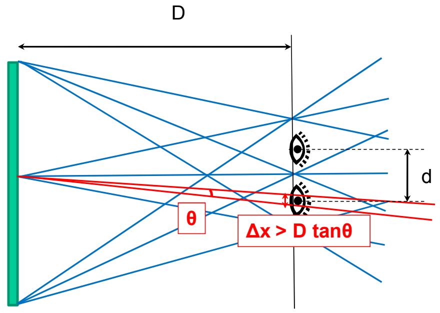

Figure 1. Main parameters for position uncertainty.

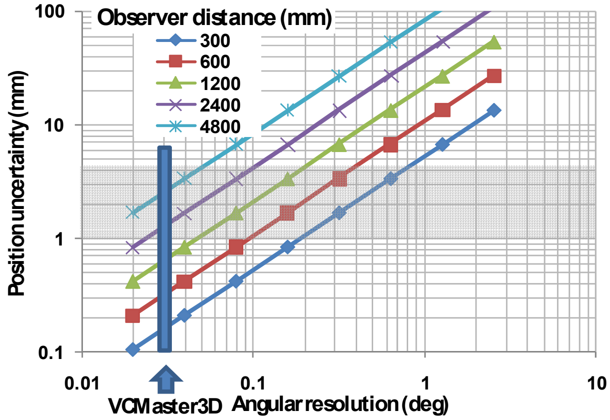

Figure 2. Position uncertainty versus angular resolution for different observer distances.

2.2. VCMaster3D characteristics

Fourier optics converts the angular response of a sample into a spatial information that can be imaged by a 2D sensor. In practice, the Fourier optics is an achromatic combination of different lenses that collects quasi all the light coming from the display and focus each incident angle on an intermediate Fourier plane. A field lens and an imaging lens are then used to re-image the first Fourier plane on the CCD sensor. The design used by ELDIM includes a field iris before the sensor which is complex conjugate of the display surface and allows adjusting the measurement spot size independently of the angular aperture. As a consequence, the measurement spot size varies with the angle to ensure high collection efficiency even for large incidence angles. The size of

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the measuring spot is easily adapted by the iris diameter. For 3D display characterization, we need to be able to measure all the views of the display without moving the instrument. So, the spot size must then be sufficiently large to include tens of pixels for each view of the display. For VCMaster-3D, a maximum spot diameter of 4mm is achieved. The optimum working distance is fixed to 15mm. This distance ensures that the measured spot is always centered at the same location for each incidence angle but is not critical parameter. The main specifications of VCMaster-3D are summarized in Table 1.

Field	**Incidence angle Azimuth angle**	**±50° 0-360°**
Measuring area	**Maximum diameter**	**4mm**
Working distance	**Optimal for fixed spot position**	**15mm**
Spot size	**Automatic or manual**	**4, 2, 1and 0.5mm**
Accuracy	**Angular resolution (deg) Luminance Chromaticity**	**<0.03° ±3% 0.005 (for any stimulus)**

Table 1. VCMaster3D main specifications

2.3. Theoretical & measured angular resolution

The main feature of the new instrument is its very high angular resolution below 0.03° compared to 0.5° for standard ELDIM system °. This specification has been achieved thanks to a specific optical design including aspheric lenses and a 16M pixels CCD camera. On figure 3 we have reported the theoretical responses of VCMaster3D and conventional EZContrastXL88 optical systems to a perfectly rectangular step applied on axis. We can see that the step is much more correctly resolved using the new instrument than with standard system where the spreading extends to more than ±0.6°.

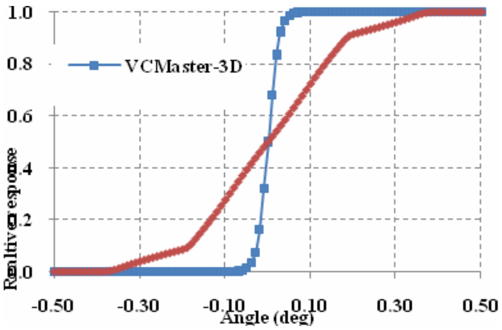

Figure 3. Angular theoretical response of the optics to a rectangular step applied on axis.

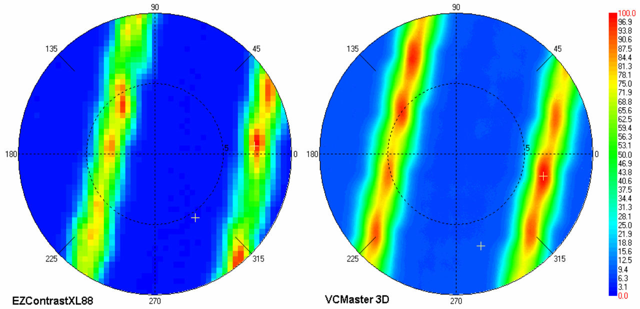

Figure 4. Luminance measurement of one view on 30" parallax barrier 3DTV measured using EZContrastXL88 system (left) and VCMaster3D (right)

This much higher angular resolution is confirmed by the measurements on real samples. Figure 4 reports the case of an 8 views 30' 3D TV based on parallax barrier technology. In this case, each view covers a very limited angular range in the viewing angle space. In this particular case only VCMaster3D is capable of providing a clear picture of the light behavior along the barriers. The detected periodic modulation is due to the stepping shape of the barriers and has strong consequences on the 3D properties.

2.4. Parasitic light and crosstalk

As shown in figure 4, the emissive properties of autostereoscopic displays generally show strong angular variations when each view is measured separately. Valuable contrasts between views (or crosstalk) can only be measured if the minimum between angular rays is not over-estimated because of parasitic light generated in the equipment by light coming from luminous angular regions . The level of parasitic light in Fourier optics is dependent on both the optical design and the quality of the lenses. In ELDIM standard systems this level is below 1% in quasi all the situations but for 3D displays it is not sufficient. One practical example obtained on a small NEC display [8] is reported in figure 5. The comparison between EZContrastXL88 and VCMaster3D measurements for the same view at the same location shows a factor two difference in the minimums of luminance. The excellent crosstalk of this display has then been underestimated by a factor of 2 using the standard instrument. It shows again that dedicated instrument is mandatory for accurate 3D display characterization.

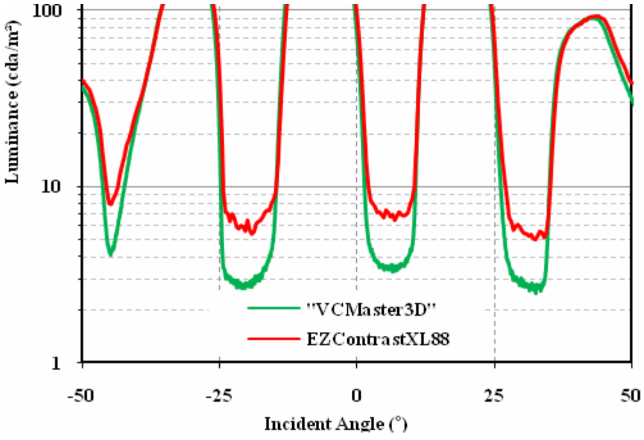

Figure 5. Horizontal cross section measured on NEC twin view 3D display with EZContrastXL88 and VCMaster3D

3. Experimental results

We focus here on an important feature of the autostereoscopic 3D displays, the accuracy of the geometric correction that allows seeing all the surface of the display in 3D from the same Qualified Stereoscopic Viewing Space QSVS. Indeed, it not sufficient that the center of display emits light properly for each eye of the observer. The angular emission of the display must be spatially adjusted so as to provide respectively the same view in the same eye of the oberver from all over the display whatever the position of the observer is in the QSVS.

3.1. Observer computation

Using Fourier optics viewing angle measurements makes it possible to calculate the light arriving from one display location to an observer located in front of the display. The observer and the measurement points are defined by their coordinates in the XYZ referential (cf. figure 6). We report hereafter computation in the different planes defined hereafter.

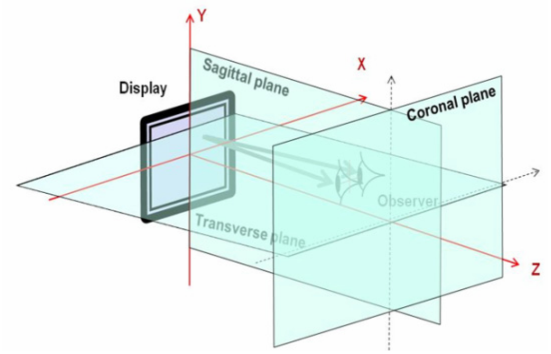

Figure 6. Definition of the planes for observer simulation

We first calculate the angular contrast $C_i(\theta,\varphi)$ for one view with regards to the others and the 3D contrast $C_{i,j}(\theta,\varphi)$ using the following formulas detailed in [6-7]:

$$C_i(\theta,\varphi) = \frac{Y_i(\theta,\varphi) - Y_B(\theta,\varphi)}{\frac{1}{N-1}\sum_{j\neq i}(Y_j(\theta,\varphi) - Y_B(\theta,\varphi))}$$

$$C^{i,j}(\theta,\varphi) = \sqrt{C^i_R(\theta_R,\varphi_R) * C^j_L(\theta_L,\varphi_L)}$$

These expressions can be used for more than one measurement location. The calculation is made for each location separately and, since the contrast must be high for all the locations we take the minimum value between each location [7].

3.2. Small NEC twin view display

The first example concerns a twin view 3.1’ LCD 3D display based on lenticular technology and with HDDP arrangement [8]. This display exhibits an excellent 3D angular contrast (85) but also perfect geometric correction. To check this second point we have acquired viewing angle measurements at center, left and right sides of the display. The resulting contrasts for left and right eyes in the transversal median plane are reported in figure 7.

They show three main qualified viewing spaces for both eyes that intersect on a quite large volume where correct binocular result will be ensured as shown in figure 8. The QSVS is of course smaller than the one obtained with only one central measurement (top of figure 8) but it is extremely high for this type of display. The geometric correction in the horizontal plane of the display is therefore very good.

3.3. 24’ 3D TV

For large 3D displays the situation can be much different especially when there are based on a standard LCD panel and additional parallax barriers or lenticular lenses. One of the main problems in this type of technology is to align correctly the barriers or the lenses on the panel to ensure optimum geometry corrections. We examine here the case of commercial 8 views lenticular lenses 3D display TV. This large size TV is based on a high resolution standard LCD panel with additional lenticular lenses. The announced working distance is about 3 meters for a display size of 24”. The display has been measured at five different locations: center, right side, left side, top and bottom.

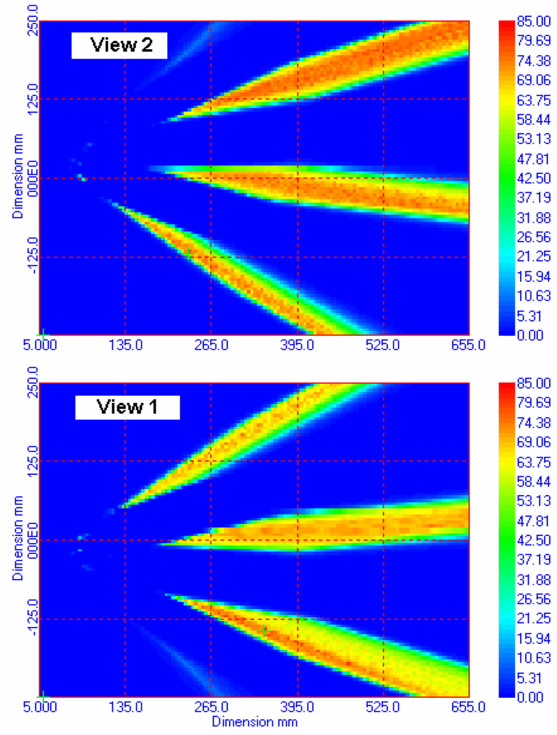

Figure 7. Contrast for left (view 1) and right (view 2) eyes in the transversal plane calculated for 3 locations

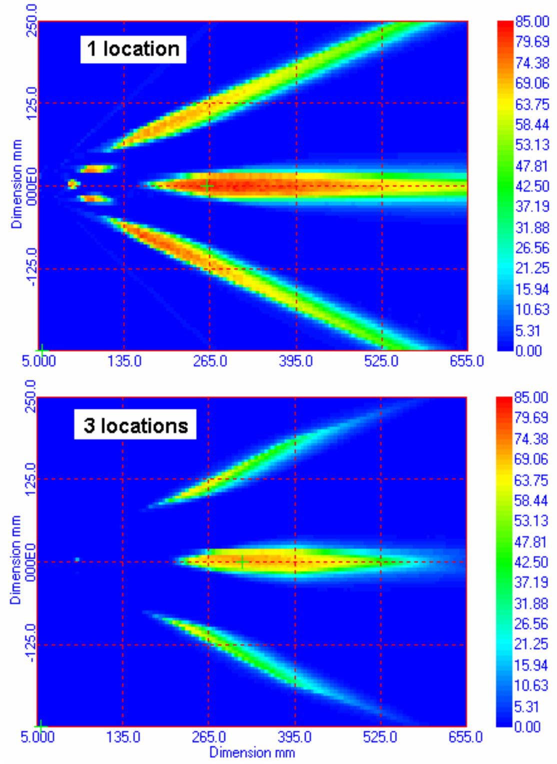

Figure 8. 3D Contrast in the transversal plane for central location and three locations (center, left and right sides).

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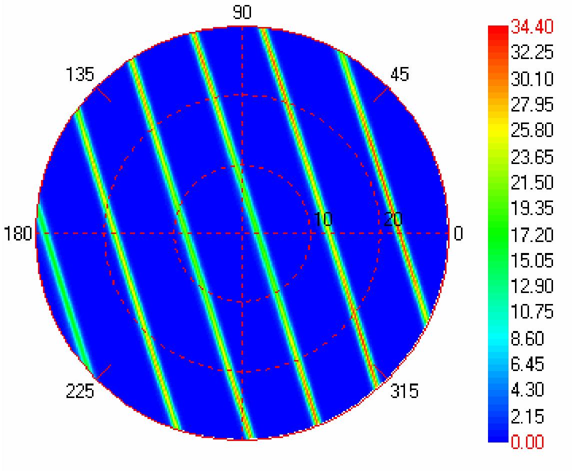

Figure 9. Angular contrast for view 1 at central location.

The measured angular contrast for view 1 is reported in figure 9. We detect very sharp linear rays tilted with regards to the vertical of the display. This tilt corresponds to the alignment direction of the lenses and is chosen to obtain homogeneous horizontal and vertical resolutions. The lens spacing is calculated to correct the emission along the horizontal direction and the geometric correction along this direction is acceptable.

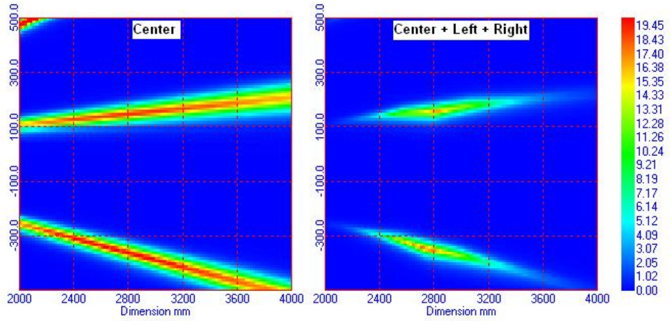

Figure 10. 3D contrast between view 1 and 2 in the median transverse plane for center and 3 points simulations.

This point is verified calculating the QSVS defined by the three horizontal locations. Nevertheless the vertical direction cannot be corrected except using variable lateral spacing along the lenses. In practice it is not the case and so vertical direction is not corrected. This point is easily seen comparing the QSVS obtained for the central location and the top location for example (see figure 10). In the sagittal plane there is no real interception between the two QSVS. It means that there is no location in front of the display that ensures a perfect binocular contrast for all the display surface along vertical.

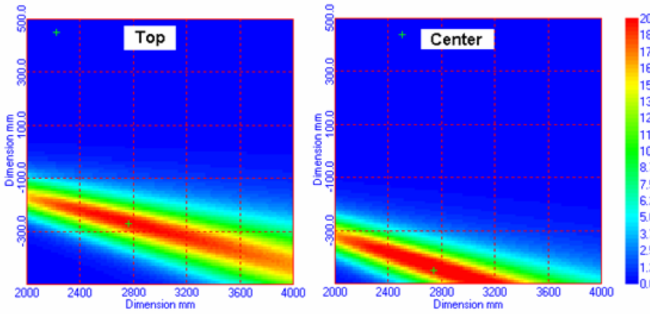

Figure 11. 3D contrast between view 1 and 2 in the sagittal plane for central and top measurement locations.

4. Conclusions

A new characterization system, VCMaster-3D, dedicated to 3D displays has been presented. With an excellent angular resolution, it is the most advanced solution to characterize precisely 3D displays. Calculation of 3D contrast in the observer space using multi-location measurements is mandatory to measure the QSVS and to verify if the emission properties of the display are in line with the design.

5. References

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