Viewing angle and spectral characterization of LCDs and their components

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ABSTRACT

A new Fourier optics system capable to measure spectral information at each incidence and azimuth angles is presented. In reasonable measurement times, a full viewing angle pattern of radiance at 31 wavelengths regularly distributed in the visible range is obtained. Full polarization analysis of the light at each wavelength is possible. Paper focuses on grey level and polarization analyses of one LCD display in order to show some of the possibilities of the new instrument.

1. INTRODUCTION

Fourier optics based systems are now widely used for color and luminance viewing angle measurements of many types of displays and components. The measurement speed and the large amount of data are key parameters to estimate viewing angle properties rapidly and accurately. Nevertheless, standard color measurements, even if perfectly adjusted to the human eye sensitive, are quite restrictive compared to the complex spectral stimuli always emitted by any kind of display. A multispectral analysis with 20 to 30 channels in the visible range can be helpful. For digital color imaging and color reproduction this approach has been used with success [1-2]. Some attempts have been made recently to characterize backlights with hyper-spectral camera [3]. Transmission of display components such as polarizer and diffusion films, can exhibit complex spectral behaviors that need to be taken into account for precise predictions of the emissive properties. Recently a new generation of viewing angle systems EZContrastMS from ELDIM capable to provide multispectral information on the full cone of view of displays in reasonable measurement times has been presented [4]. This system can provide radiance information but also complete polarization analysis versus wavelength. We focus on this aspect in the present paper.

2. EXPERIMENTAL DETAILS

The new system is based on the well known Fourier transform EZContrast viewing angle instruments proposed by ELDIM for more than ten years. Compared to standard instrument the 5 color filters are replaced by 31 band pass filters regularly distributed in the visible range. The system makes automatically a quasi spectral image of the full Fourier plane at each filter and the sequence is repeated for all the filters. The system is calibrated in an absolute way to reconstruct the spectral radiance at each incidence and azimuth angle. Complete measurement sequence takes less than 3 minutes for 100Cd/m^2 white source. Color and luminance properties can be recalculated with an excellent accuracy. The system includes also different polarizers and waveplates in the same way as standard systems [5], to allow full polarization analysis at each filter wavelength. Polarization ellipticity, polarization direction and polarization degree are then available in the full viewing angle for each wavelength.

3. EXPERIMENTAL RESULTS

3.1 Introduction

In the present paper, we have decided to measure the same LCD display in three different conditions to show the new possibilities of the instrument: a first set of radiance measurements is made on ON state and OFF state. Then grey level analysis is made. Finally polarization dependence without top polarizer is measured.

3.2 Luminance Analysis of one LCD

One example of radiance spectrum measured at normal incidence on ON state is reported in figure 1. The LCD used in this study includes a CCFL backlight and the different emission lines of this type of lamp are of course detected.

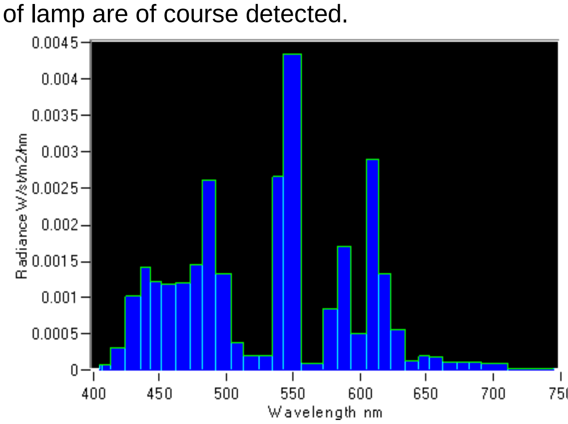

Fig. 1 Absolute radiance of ON state at normal incidence

This type of information is obtained at each incidence and azimuth angle of the full viewing angle cone of the display and can be used to evaluate in great details the emissive performances of the display. For example, not only the luminance contrast ratio but also the radiance contrast ratio can be calculated at each wavelength. One example is reported in figure 2. ON and OFF angular radiance distribution can be used to calculate the radiance contrast ratio at each wavelength (549 and 477nm in figure 2). The contrast degradation in the blue can be point out in this example.

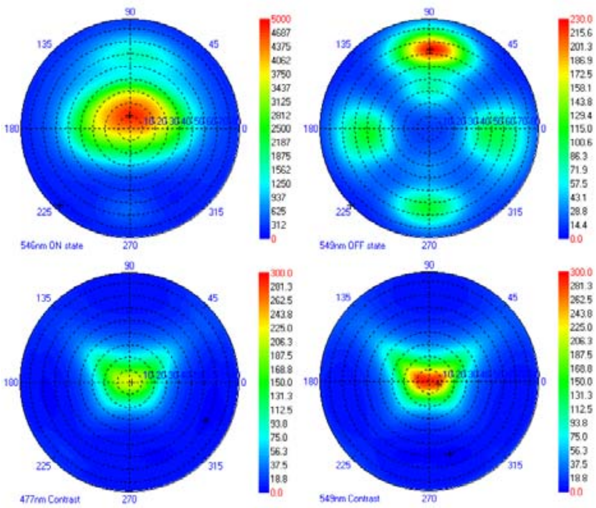

Fig. 2 Radiance at 549nm for ON state (top left) and OFF (top right) and radiance contrast at 477nm (bottom left) and 549nm (bottom right)

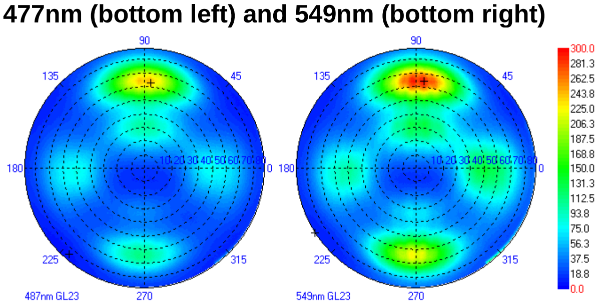

Fig. 3 Radiance pattern at 487nm (left) and 549nm (right) for grey level 23.

3.3 Grey Scale multispectral analysis

Isocontrast curves are usually used to evaluate the viewing angle characteristics of LCDs. For grey level scales images, this is not sufficient. Viewing angle grey level analysis of luminance and lightness measured using Fourier optics instrument has been proposed earlier [6]. The same type of analysis can be made using EZContrastMS using radiance instead of luminance or lightness. As shown in figure 3, the angular pattern of radiance for a given grey level is dependent on wavelength. It is then possible to make a complete grey level analysis of the LCD emission at each wavelength. Fine dependence versus wavelength and incidence can be detected as shown in figures 4 & 5.

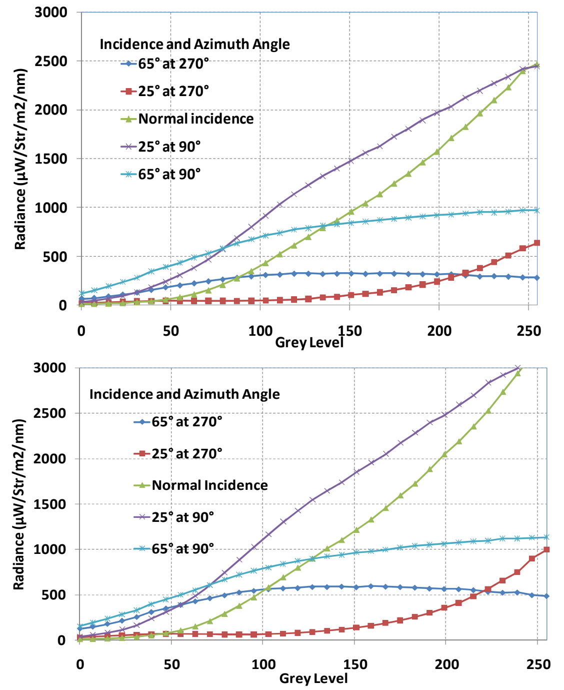

Fig. 4 Grey level dependence of the radiance at 487nm (top) and 549nm (bottom): five angles are selected.

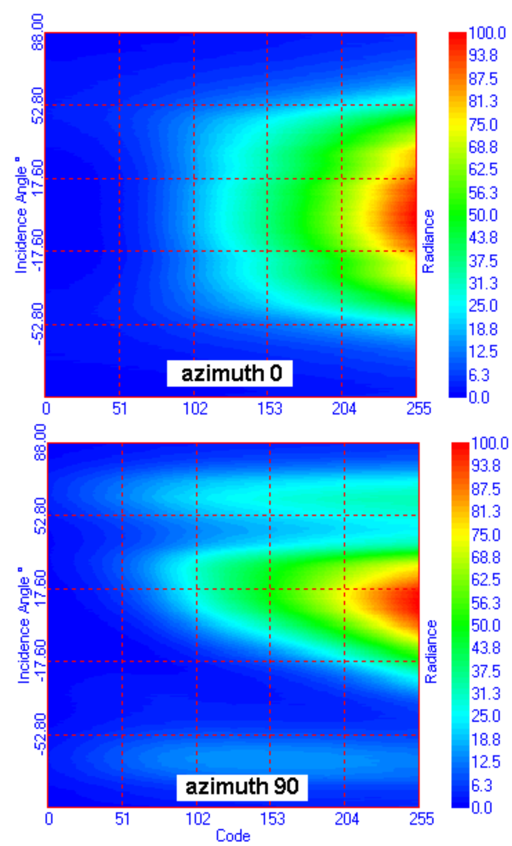

Fig. 5 Grey level dependence of radiance along azimuth 0 and azimuth 90. The wavelength is fixed at 549nm and values are relative.

3.2 Polarization analysis

Polarization analysis of the light emitted by LCDs is also very informative on the efficiency of the liquid crystal cell as polarization modulator. We have already shown that unpolarized light detected in OFF state is directly related to the quality of the black level of the display [5]. Another way to follow in details the crystal cell switching is to remove the last polarizer of the LCD and to measure the polarization state versus grey level. On example is reported in figure 5. We see directly that the OFF state is characterized by quasi linear polarized light in particular near normal incidence. The liquid crystal cell rotation acts as a waveplate and the light becomes nearly circular polarized for ON state. The polarization degree is also slightly affected by the crystal cell rotation: it is nearly 1 for OFF state and decrease down to 0.85 for ON state.

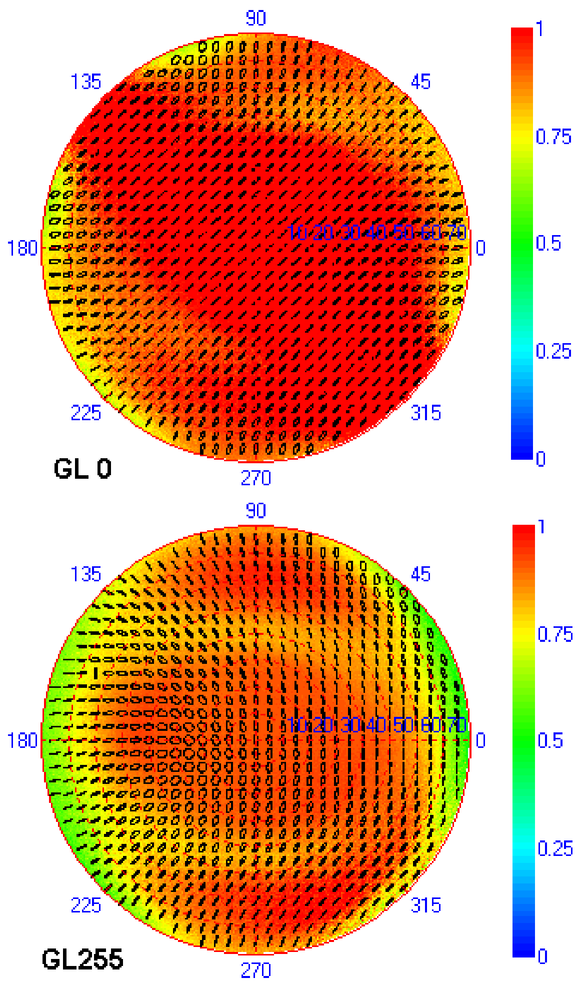

Fig. 5 Polarization analysis of LCD display without last polarizer at 549nm: the polarization degree is reported in color scale.

The polarization rotation depends on the incidence and azimuth angles and drives the viewing angle of the display. As shown in figure 5, the polarization state of ON state is far to be ideal. In particular the light is far to be perfectly circular and strongly depends on the angle. To emphasize this point, we have reported the data measured along the 45° azimuth versus incidence angle and grey level (cf. figure 6). The wavelength is fixed at 549nm as for figure 5. We see that the maximum of ellipticity is not for normal incidence and does not reach 45°. The degradation of polarization degree at high angles drives the angle of view of the display.

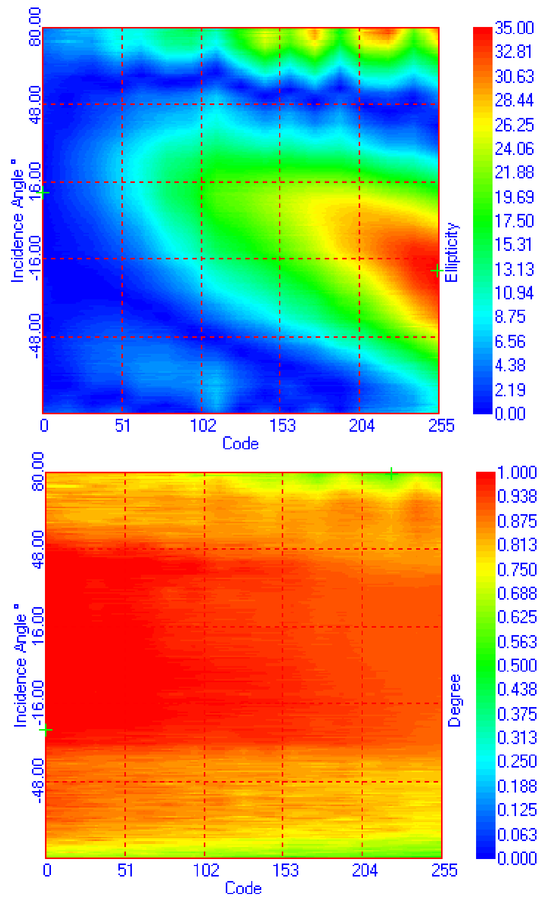

Fig. 6 Polarization analysis of LCD display without last polarizer: ellipticity and polarization degree are reported versus grey level and incidence angle (the azimuth is fixed at 45°and the wavelength at 549nm).

All these data can be used to evaluate the best top surface polarizer. One easy way to read the polarization data is to use the Poincare sphere as shown in figure 7. The evolution of the S1 and S2 Stokes vector is characteristic of the polarization rotation of the crystal cell and the influence of the incidence angle is particularly clear. The influence of the LC can be decomposed in an equivalent optical retardation and one rotation [7]. These two parameters can be easily driven from the present data. The rotation is in particular strongly dependent on the angle. The retardation is exactly at 45° only for +50° incidence in this case. The rotation and the orientation of a combine waveplate and polarizer to complete the LCD in the most efficient conditions can be derived.

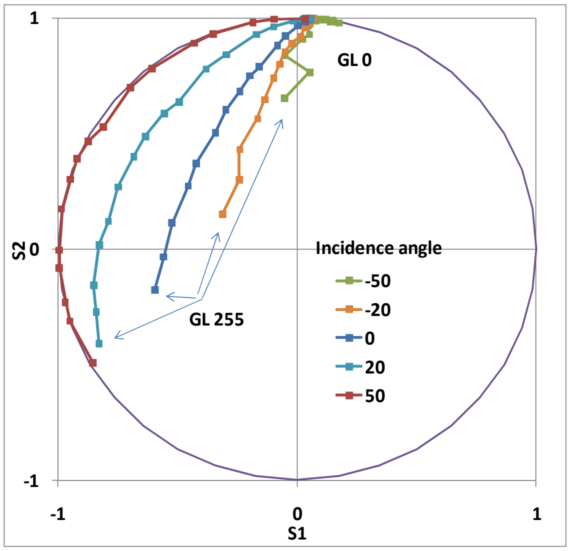

Fig. 7 Evolution of stokes vector versus grey level at different incidence along 45° azimuth (the wavelength is fixed at 549nm).

Of course the efficient of the display must be maximized for all the visible range. Using EZContrastMS, the same polarization analysis can be made at all the wavelengths of the instrument. One example is reported in figure 8. We report the ellipticity and orientation of the light emitted by the display versus grey level and at 3 wavelengths (549nm already used in figures 6-7, 487nm and 609nm). We detect small dependence of ellipticity and orientation versus wavelength as waited for a liquid crystal cell. The variations are essentially due to the variation of the optical indices of the LC versus wavelength. These variations must nevertheless be taken into account to ensure optimal performances at all wavelengths. For the present LCD it is clearly not the case as we have seen on the grey level analysis of the radiance.

4. CONCLUSIONS

New features for the characterization of LCD using multispectral EZContrastMS system are presented. In addition to provide most efficient data in terms of luminance and color, precise analysis of the display performance can be made versus wavelength and grey levels. The capacity to analyse the polarization state of the light is also extremely helpful to understand the LCD behavior. If we remove the top LCD polarizer the rotation of the liquid crystal cell versus all parameters can be measured (angles, grey level, and wavelength). It is possible then to evaluate the best top waveplate and polarizer to optimize the performances of the display. Polarization grey level analysis can help to optimize the liquid crystal cell and its components.

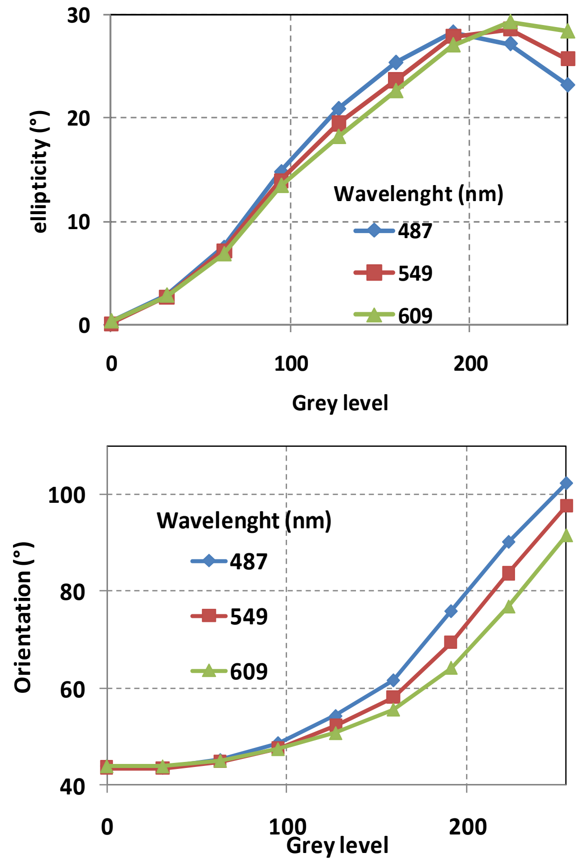

Fig. 8 Normal incidence evolution of ellipticity and orientation versus grey level at different wavelength

5. REFERENCES

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