New generation of imaging colorimeter and imaging polarimeter

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(2 line spacing)

Abstract

We present a new generation of imaging colorimeter that ensures improved accuracy and sensitivity for shorter measurement times. The imaging optics is telecentric on the sensor and allows measurements at any distances without additional calibration. A new technology is used to make the color filters and flat densities. Imaging polarimetry at fixed wavelength is also possible with the same instrument.

1. Introduction

Imaging colorimeter is one of the most common instruments to characterize the homogeneity of the emission of any kind of display. User requirements are generally on color accuracy, high sensitivity and very short measurement times. Color accuracy is the ability of the system to match the three CIE curves for all wavelengths in the visible range. Solutions using color filter embedded in the sensor never work for all luminous stimuli. ELDIM has been using color filters designed to match the sensor response of each CCD and monochrome sensor in all its system since many years [1]. Up to now these color filters are realized with stacks of color glasses and work by pure absorption. The sensitivity depends on the CCD efficiency and on the transmittance of the color filters. Even if this solution gives excellent accuracy, any further improvement can come mainly from the transmittance of the filters [2]. Recently ELDIM has introduced the capacity to measure spectral radiance and polarization state of the light in its Fourier optics viewing angle instruments [3]. Up to now imaging polarization has not been used to characterize display homogeneity. It is surprising since LCDs are essentially polarizer modulators but no practical system was available up to now. In the present paper we introduce a new imaging colorimeter that can also make imaging polarimetry. Some technical details are given hereafter with some first results on imaging polarization.

2. Experimental

Imaging colorimeters are all based on CCD sensors and generally color filters. The difference between the systems lays in the accuracy, the signal over noise ratio, the spatial resolution and the quality of the imaging optics. UMaster is based on a Peltier cooled CCD sensor with true 16-bit analog digital converter. Four color filters dedicated to each CCD sensor are mounted on a motorized color wheel. A second motorized wheel with flat densities is also available for automatic adjustment to the source luminance. Color filters are realized using complex multilayer stacks of transparent layers deposited on one thin substrate using ion assisted electron beam evaporation (cf. figure 1). A better adjustment to the CIE curves, is obtained with only one filter for luminance and the total transmittance is improved for all components compared to the color glass solution (by a factor of 2 or 3 depending on the filter). The neutral densities are also realized with the same technique and show better characteristics (cf. figure 2). The imaging optics is telecentric on the sensor, which ensures the same incidence for all the rays crossing the filters and so the same spectral response. In addition the flux is quasi independent of the object distance while conventional optic can suffer from up to 20% reduction at short distance. Consequently only one calibration is required for all situations. The system includes also different polarizers and wave-plates to allow polarization imaging at different wavelengths.

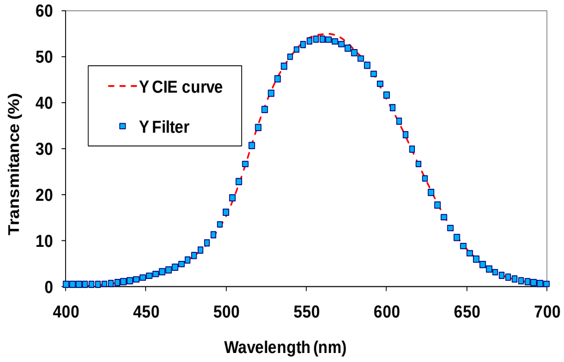

Fig. 1. Spectral response of UMaster compared to Y CIE curve.

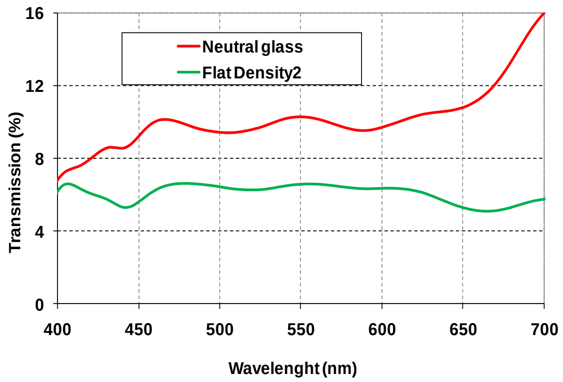

Fig. 2. Flattened neutral density compare to standard neutral glass filter

The polarized component of light can be defined by its elliptical coefficients (ellipticity ε and orientation α). Unpolarized light component is defined by the degree of polarization ρ given by the ratio of the intensity due to polarized component over the total light intensity. The three previous parameters can be combined with the intensity to provide the Stokes vector using:

$$S = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = I.\begin{bmatrix} 1 \\ \rho.\cos 2\varepsilon.\cos 2\alpha \\ \rho.\cos 2\varepsilon.\sin 2\alpha \\ \rho.\sin 2\varepsilon \end{bmatrix}$$

The polarization option of UMaster includes three polarizers at different orientations (0, 45 and 90°) and two wave-plates at different orientation (45 and 135°). The system makes automatically seven measurements with different polarization configurations and computes automatically the polarization parameters and the Stokes vector. The measurement is made at one given wavelength defined by a band pass filter (for example 550nm in the following). Any wavelength in the visible range is available.

3. Results and discussion

Backlight with BEF film

LCD performances are partially driven by the backlight properties in terms of homogeneity and angular emission. Backlight characterization is generally made with video colorimeters and viewing angle instruments but only on the luminance and chromaticity. In fact, even if the first element of the liquid crystal cell is a polarizer, the polarization state of the light emitted by the backlight is also important because it drives really the performances of the liquid crystal cell. The backlight measured hereafter includes a BEF layer on its surface. If the intensity of the light (Stokes vector S0 on figure 3.a) does not show any specific feature, a pseudo periodic structure is detected on the ellipticity, orientation and polarization degree across its surface (cf. figure 3b, 3c and 3d). This behavior comes probably from the BEF film and can have an important impact on the homogeneity of the LCD build with this backlight.

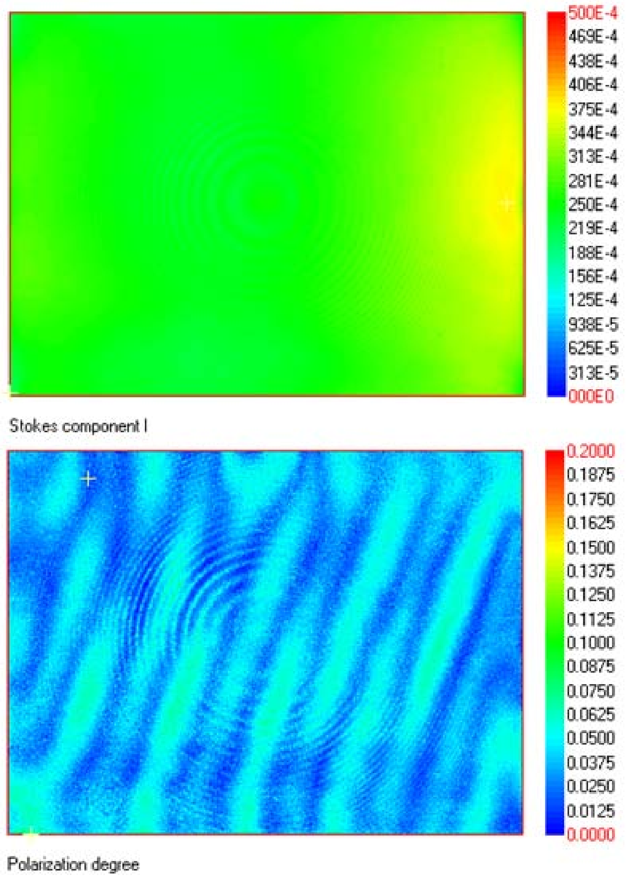

Fig. 3. Imaging polarization of a LCD backlight with BEF film measured at 550nm: Stokes vector S0 (top) and polarization degree (bottom)

LCD in OFF state

Improving OFF state is crucial for enhancing contrast across wide viewing angles. Viewing angle polarization measurements on LCDs have shown a close correlation between the luminance contrast and the degree of polarization of the light detected in OFF state [4]. The same type of measurement on the entire surface of the display gives new information. We give hereafter the example of a 15' LCD which was measured for ON state and OFF state at 550nm. For ON state the light is quasi fully polarized with very small local deviations. On the contrary, measuring OFF state allows seeing some of the imperfections of the display as shown in figure 4. Most of the light emitted by the display is not polarized (cf. figure 4.a), and the small polarized component is probably resulting from imperfections of the polarizers or the liquid crystal cell. Some inhomogeneities in the polarization ellipticity and polarization orientation are detected as shown in figure 4.b.

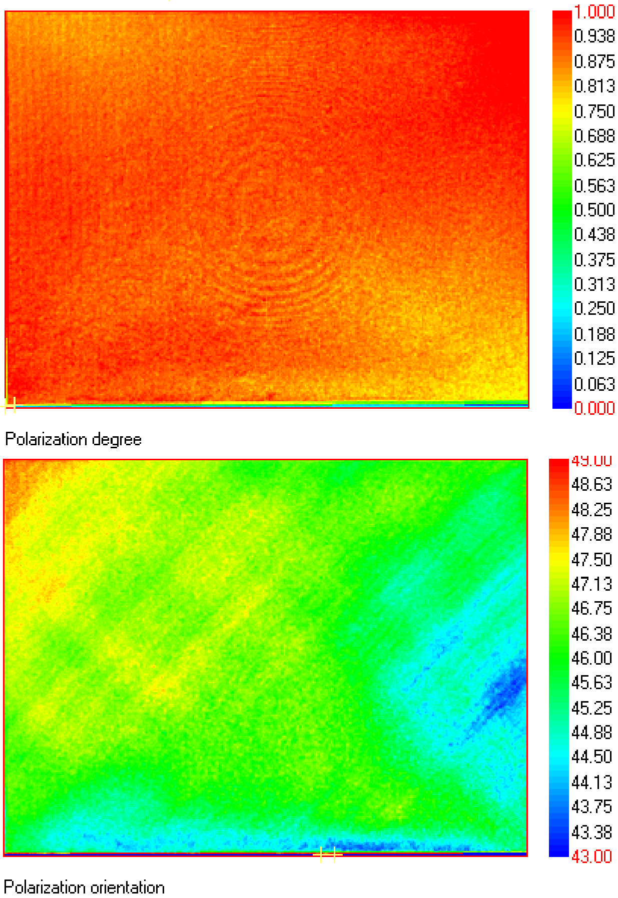

Fig.4. Imaging polarization of a LCD in OFF state measured at 550nm: polarization degree (top) and polarization orientation (bottom)

LCD without top polarizer

Polarization analysis of the light emitted by LCDs is also very informative on the efficiency of the liquid crystal cell as polarization modulator. An efficient way to follow in details the crystal cell switching is to remove the top polarizer of the LCD and measure the polarization state versus grey level. This type of study has already been done using multispectral viewing angle system [5], giving a complete analysis of the crystal cell rotation versus incidence, azimuth and wavelength. We have made the same experiment here using the UMaster system to check if the crystal cell behavior is homogeneous all over the panel surface. Some results obtained at 550nm are reported in figure 5. In the panel under investigation, the top polarizer was aligned along the +45° direction. The polarization state should be perfectly linear along -45° direction for OFF state and also perfectly linear along +45° direction for ON state. As shown in figure 5, the OFF state (grey level 0) is characterized by a strong polarization degree which is quasi homogeneous on the display surface. There is nevertheless small ellipticity at the bottom right corner of the display. When increasing the grey level values the ellipticity increases up to around 25° for grey level 128 and then decreases again to very low values for ON state but this behavior is absolutely not homogeneous on the display surface. In addition, some small inhomogeneities appear in ON state which are probably characteristic of some misalignments of the liquid crystal layer. The polarization direction follows the required behavior from ON state to OFF state but with the same type of inhomogeneities correlated with ellipticity. Finally the unpolarized light increases with the grey level from very small values for OFF state to quite large values for ON state. This type of behavior measured for the first time must be analyzed in more details and correlated with the manufacturing technology, but it will be certainly helpful in the future to increase the performances of such panels.

4. Summary

In this paper we have presented a new instrument that allows making polarization imaging in the same way as luminance or chromaticity using video-colorimeters. Interesting results have been shown for backlight and LCD displays. In particular the homogeneity of the crystal cell rotation of a LCD has been evaluated for the first time. Surprising enough it is not as homogeneous as waited on the panel measured in this study.

5. References

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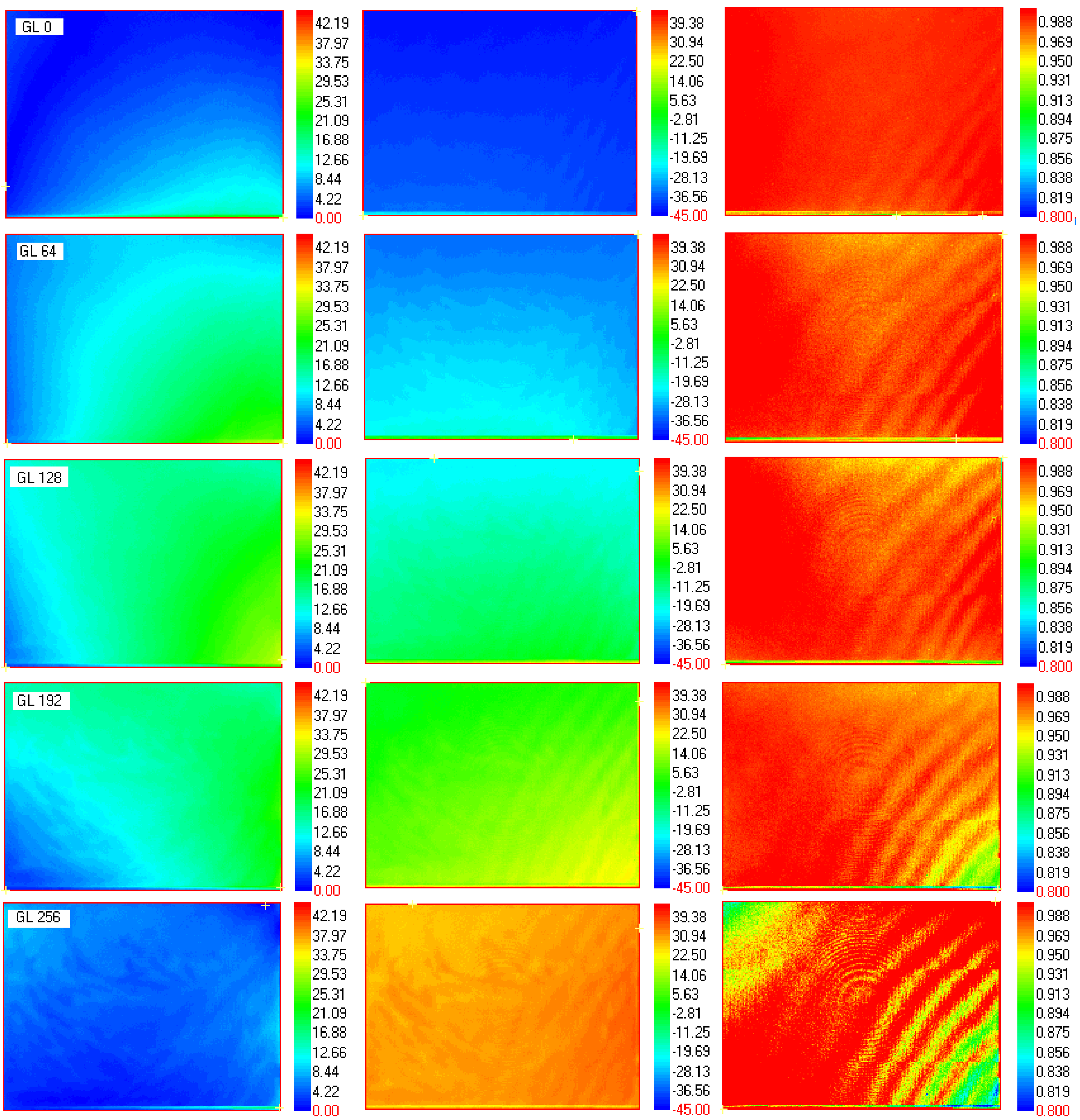

Fig.5. Polarization ellipticity (left), polarization orientation (center) and polarization degree (right) of a LCD without top polarizer and versus the grey level (0, 64, 128, 192 and 256).