11.2: Standards and Metrology for Reflective LCDs

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Abstract

This paper summarizes the existing international standards and describes the problems that are currently obstacles on the way to reproducible metrology for reflective LCDs. Identification and removal of these problems shall help establishing a well founded and reasonably applicable standard for reflective LCD-metrology. We present a simple concept for detailed characterization of the illumination conditions and introduce a compact new device that supports the required measurements with the due flexibility in illumination geometry, required robustness and reproducibility.

1. LCD-Metrology Standards

After many years of cooperative and constructive discussions, simple approaches to measuring LCDs have been standardized by the IEC SC47C / WG2 in the framework of IEC 61747 "Liquid crystal and solid-state display devices". This standard comprises the following sections: generic, sectional and blank detail specifications, visual inspection, environmental endurance test, terminology and letter symbols, essential ratings and characteristics, and finally the "Measuring Methods", however restricted to LCDs in the transmissive mode of operation. In addition to this the IEC Technical Committe 100" Multimedia Systems and Equipment" has generated the standard IEC 61966-4: "Colour measurement and management, Part 4: Equipment using liquid crystal display panels" describing a metrology for electro-optic and electro-colorimetric characteristics, lateral variations of luminance and chromaticity, variations of luminance and chromaticity with viewing-direction.

However, more than 26 years after description of the first measuring system for reflective LCDs by G. G. Barna [1] still no approved international standard is available as a basis for objective and comparable evaluation of the electro-optical and visual properties of this type of display.

Especially in the case of reflective LCDs it is hard to achieve the required reproducibility of the results because of the coupling between the apparatus providing the illumination, the receiver (i.e. detector with optics) and the device under test. This dependence of the results on the instrumentation implies that e.g. the contrast of reflective LCDs may not be an intrinsic property of the device itself, but the contrast can only be evaluated under specific and well defined illumination conditions. Any contrast value or contrast distribution supposed to characterize reflective LCDs may be meaningless without the exact specification of the measuring conditions. Especially the illumination has to be known and exactly specified with the details given below.

1.1. Reflective LCDs

These days finally there is a move to establish the optical metrology for reflective LCDs in an international standard (IEC/TC47C, WG2). This standard is supposed to cover the needs of display manufacturers in their research and development as well as the requirements of the engineers that are integrating displays into electronic devices. The standard shall provide approaches for detailed characterization of the optical properties of the sample as function of the direction of observation (e.g. BRDF and other data as required for subsequent numerical simulation), it shall provide methods for prediction of the visual performance of displays in real application situations (i.e. over a wide range of different illumination situations) and appropriate ways for testing the conformity to product specifications (i.e. acceptance screening). At the same time the metrology to be standardized must allow for measurement of the variation of all relevant electro-optical properties of reflective LCDs with viewing-direction (e.g. contrast).

The "total solution" to all problems of reflective display evaluation could be the BRDF-approach [2, 3], but measuring the BRDF as a function of all parameters (i.e. direction of light incidence and observer, wavelength of light and state of polarization, state of electrical driving for contrast evaluation, etc.) produces prohibitively large amounts of data and requires expensive instrumentation.

Provided with quite some practical experience from the past years the metrologist may take the chance and request the following features for the upcoming standard for reflective LCDs:

- applicability to a wide range of reflective displays,
- applicability to a wide range of instrumentation (e.g. goniometric, conoscopic),
- applicability to a wide range of operator skills and laboratory budgets,

ISSN/0002-0966X/02/3301-0000-$1.00+.00 © 2002 SID

- measurement of variations of optical parameters with viewing-direction (contrast, luminance, etc.),
- realistic prediction of visual performance under actual illumination conditions,
- suitable illumination schemes for acceptance-testing and screening,
- robustness: easy alignment, good repeatability and reproducibility, low uncertainty.

2. Metrology for reflective LCDs

The problems related to measuring the electro-optical properties of reflective LCDs have been know since the early attempts to characterize and optimize the variations of LCD contrast with viewing-direction. A first method for illuminating reflective LCDs during the measurement with a glass-hemisphere producing a multidirectional “diffuse” illumination was proposed by Barna in 1976 [1] and realized as a commercial product in Germany [4]. Parallel to this another goniometric approach was implemented in Japan and established in the respective national standards of the EIAJ. This second method uses a small-area source out of the specular direction of the receiver to evaluate contrast values, but variation of the optical properties of LCDs with viewing-direction are usually not obtained. It is obvious that both approaches make use of two extreme illumination situations: multi-directional "diffuse" and point-source illumination, but the results obtained are still subject to superficial comparison and to commercial interests, since often the conditions under which the "numbers" have been generated are not known nor are the respective consequences and implications understood.

The reasons for the large differences in the results that are obtained with these two approaches in the case of reflective LCDs have been analyzed and the results are published e.g. in [4]. This paper also shows that the intrinsic variations of contrast with viewing-direction, known e.g. from transmissive measurements, can only be reproduced in the reflective mode of operation under multi-directional ("diffuse") illumination.

Conoscopic methods, which complement the goniometric approach since a couple of years, exhibit a range of specific problems of their own due to the fact that illumination of the sample and detection and analysis of the reflected light is achieved through the same optical path [5].

3. Illumination geometries

There seems to be an unlimited number of geometries for illuminating reflective LCDs during the measurement, but which is the right one and shall be chosen ?

The analysis is quite simple for stationary devices like computer monitors that sit on a desk in a typical office .We

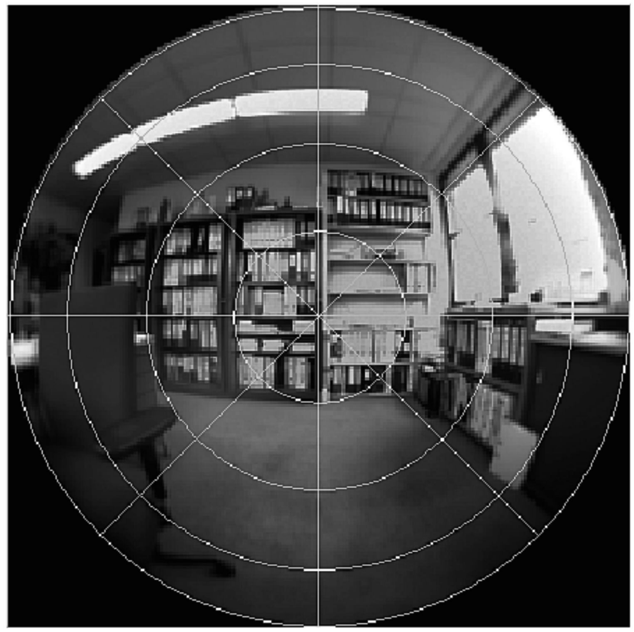

Figure 1: Gray-shade representation of the directional luminance distribution in a typical office as "seen" by a desktop computer monitor, shown in a polar coordinate system (max. inclination = 80°).

can check the illumination condition in this case by just “looking through the eyes of the monitor” with an adequately corrected electronic camera with wide-angle fish-eye lens. A typical example for the directional distribution of illumination at an office workplace is shown in Figure 1. The most dominant light sources are the ceiling luminaires and the daylight entering through the windows. A variation of luminance between 100 cd/m^2 (in the ceiling areas and on the floor) and maximum values of 30 kcd/m^2 (windows) was measured. This measurement does not resolve the different spectra of the dominant sources, the fluorescent tubes inside the ceiling luminaires and the daylight, because a three-filter R, G, B camera was used.. With this approach and with additional spectral analysis the characteristics of illumination can be characterized in the following terms and quantities:

- Intensity (e.g. luminance) and spectrum versus direction of light incidence and versus position on the sample (lateral variations),
- Temporal characteristics (short and long-term variations) of intensity and spectrum.

This example shows that even a simple typical indoor scenario exhibits a wide dynamic range for the intensity with a directional distribution that is different from case to case and with different sources and spectra (daylight, incandescent lamps, discharge lamps, etc).

When we have a look at portable devices the situation becomes even more variable, because neither the orientation of the display nor the direction with respect to the user is generally defined. Good performance of displays in portable devices is requested for all locations (indoor, outdoor, blue sky, cloudy, etc.) and a range of illumination conditions that is beyond any definition. But how can we obtain a typical geometry for the measurement ?

Since the variety of real-life situations is much to large to condense a single "typical case" from them, we have to consider which special cases might be of interest (depending on the final application of the product), even if they do not occur exactly in reality.

One possibility with distinct advantages for the signal-to-noise ratio of the detector is illumination from all directions, often called "diffuse*" illumination [8]. This geometry, successfully used in the display industry for more than 20 years, yields lower contrast values than other, non-diffuse illumination schemes as described in [2].

The other extreme case is a "point-source" (i.e. small size with respect to distance from measuring spot) that illuminates the sample from a given direction. Suitable choice of the direction of observation (i.e. receiver direction) can produce impressive values for the contrast as explained in [2].

This constitutes the current dilemma in reflective display metrology: we may choose between two illumination geometries, one of them providing high contrast values (without characterization of the variations of contrast with viewing-direction), the other one yielding moderate contrast values while at the same time allowing for detailed evaluation of variations with viewing-direction.

4. Results

4.1. Dome-approach

The solution proposed here is a flexible concept and device for easy realization of a wide range of different illumination geometries including the listed extreme cases. This device can be modified or exchanged whenever required or requested instead of being limited to one of the above listed extreme cases. Together with this additional degree of freedom in the measuring setup comes the necessity to exactly specify the illumination scheme that has been applied during the measurement.

The basic concept of such a flexible illumination device is derived from the luminance distribution shown in Figure 1. We can map all light sources in the surroundings of the display into luminance sources on a hemisphere with the measuring spot in its center and realize this arrangement with a dome-construction as shown in Figure 2. The outer dome is the carrier for the light sources and for the receivers while the inner dome is shaping the directional and lateral distribution of light. This is achieved via either

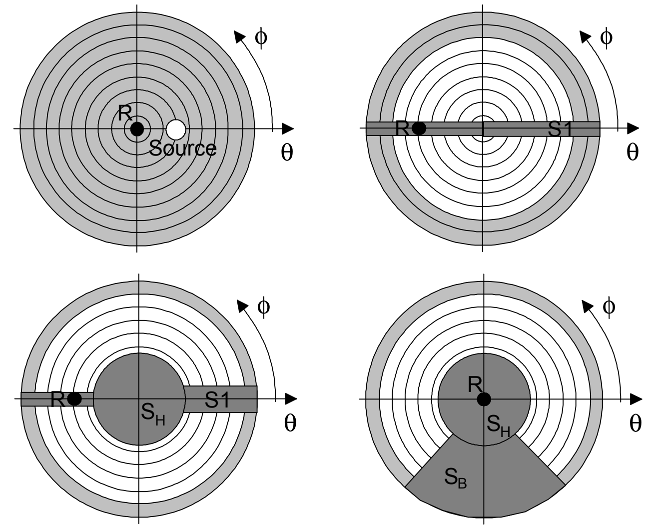

Figure 2: Sketch of the realization of a versatile setup for illumination and detection with a double-layer dome centered around the measuring spot.

scattering material for homogenization of the light distribution or via absorbing material for generation of shadow regions (e.g. head of observer) [8]. Clear transparent material is provided for discrete sources and for the receivers. The light sources can be realized as halogenic bulbs, LEDs, circular fluorescent tubes, etc. or light can be supplied from a remote source via light guiding fibers. This concept thus allows for mixing light sources with different spectra as often encountered in real application situations (see Fig. 1, fluorescent lamps and daylight).

The dome shown in Figure 2 also carries a multitude of receivers which are pointing toward the measuring spot on the sample from different directions for collection of the light emerging from the sample. All receivers are connected to a special multichannel spectrometer with simultaneous fast photometric detection [9].

Once a typical illumination situation has been identified for a special application, this situation can be reproduced with the components of the DisplayDome™ [9].The light from the object of measurement is analyzed in terms of luminance and spectral distribution for a multitude of viewing-directions. This configuration of the device is also well suited for acceptance screening of a large number of samples and for checking the conformity to product specifications under special illumination conditions. With a motorized receiver with variable angle of inclination and rotation of the sample, the viewing-cone of the display can be scanned in a conventional way (goniometric method) as required for high resolution BRDF evaluations [9].

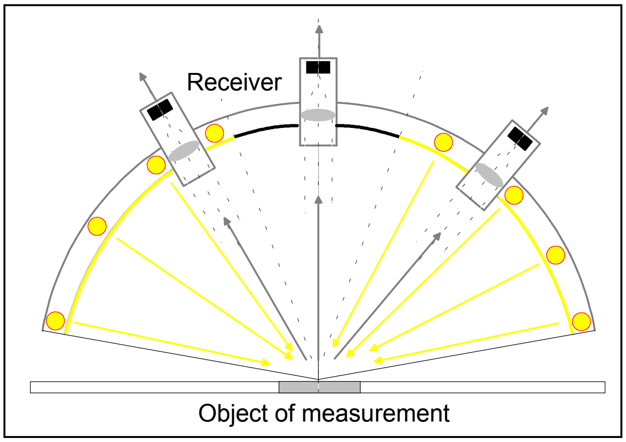

Figure 3: Polar representation of four basic illumination geometries: (TL) “point-source”illumination at 30° with normal receiver R, (TR) multidirectional illumination with shade S_1 and variable receiver inclination, (BL) multi-directional illumination with head-shade S_H and (BR) illumination with shoulder-shade of observer S_B

4.2. Specification of illumination geometries

In order to enable adaption of the illumination geometries to a wide range of application situations without adding further confusion, the illumination geometry has be specified in detail. This can be achieved by measurement of the quantities of interest (e.g. luminance, spectra, chromaticity etc.) of the measuring spot on the sample as a function of direction of light incidence and graphical representation of all resulting scalar quantities in a polar coordinate system as shown in Figure 3. just as in the case of contrast, luminance etc. of the sample.

Figure 3 shows the illumination from the perspective of the measuring spot on the sample for several typical cases. The sample is illuminated from the bright regions (i.e. directions) with the dark regions indicating shadow without light incidence.

The horizontal shade containing the receiver optics R (top-right, bottom-left) represents the slit in the dome through which the receiver is collecting light emerging from the display under test. When the receiver has a fixed orientation, the slit is not required and a shade is caused only by the aperture of the receiver (black circle in top-left, bottom-right).

The shadow S_1 provided for suppression of unwanted reflections from the upper surface of the display under test has a variable width to allow adjustment to various shapes of the haze-component of the anti-glare layer [6]. For inclusion of such surface reflections into the evaluation the shade S_1 can be completely removed.

A special geometry of illumination, as experienced by a reflective display in a portable application is shown in Figure 3, bottom-right. In addition to the shadow cast by the head of the observer S_H, the shade of the shoulders S_B is also included. The receiver is assumed to be in the center of the head. Depending on the distance from display to observer the dimensions of the shade-regions can to be adapted.

Further specifications are due for temporal variations of the illumination system as listed above.

5. Conclusion

We have introduced a versatile and flexible approach to realization of a wide range of illumination geometries and a concept for specification of the illumination conditions. This allows for more realistic modeling of actual application scenarios during the measurement.

6. Literature References

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* The term “diffuse” is suggests light incidence from all directions (i.e. hemispherically), but does not specify how the intensity varies within the cone of incidence; “isotropically diffuse” means “from all directions with constant intensity”.

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