https://doi.org/10.2352/ISSN.2470-1173.2019.6.MAAP-486

Accurate physico-realistic ray tracing simulation of displays

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Abstract

Physico-realistic simulation of any type of display needs to take into account not only its emissive properties but also its reflective properties which can play a key role in outdoor situations for example. We discuss a method based on Fourier optics viewing angle instruments capable to measure the emissive properties of a display for quasi-all its viewing angle and also its reflective properties versus angle and wavelength very rapidly. More precisely the spectral BRDF of the display surface is measured at different incident angles with a good angular resolution to be able to simulate accurately the unwanted reflections that corrupt display contrast and color. Thanks to the angular dependence, the display aspect for an observer anywhere in front of it can be obtained rapidly for any color image and the impact of the different imperfections can be visualized and quantified. Same experimental data are use in a new generation of spectral ray tracing software. The ray-tracing accuracy is checked by simulations of color images and comparison to analytical calculation of the light emitted and reflected by each pixel of the display.

Introduction

The intrinsic emissive properties of the displays are generally measured under darkroom conditions. However, almost no application of displays is intended for use in total darkness. On the contrary many applications are intended for bright sunlight (phones, tablets, notebooks, vehicle displays...) and everyone experience difficulties in such situations. Up to now different methods have been defined to quantify some reflective characteristics of displays using specific collimated or diffused daylight sources on goniometric benches [1-2]. Measurements with lamps in the lab cannot cover all the scenarios and there is no prediction capacity with other illumination conditions. In addition, the result cannot be clearly connected to the physical properties of the display.

With the development of spectral ray tracing software, the need of reflective measurement properties of any type of surface has becoming important. Classical method is based on spectral BRDF measurements realized with goniometric systems which are very time consuming. We have introduced the use of Fourier optics multispectral system to make rapidly this type of measurement with an excellent angular resolution [3]. We have already used this type of measurement made on a display surface and coupled with color characterization of its emissive properties to compute its display aspect under any illumination conditions [4-5].

In the following we present a new ray-tracing commercial software Omen Render that make spectral simulations using directly the color and spectral measurement results to obtain accurate simulation of any type of display with any type of illumination environment. The measurement techniques are discussed in a first part. Then the ray tracing simulations results obtained in very simple configurations are compared to analytical results obtained with the same measurements.

Experimental techniques

Multispectral viewing angle measurements

The first Fourier optics viewing angle measurement system was first publicly introduced by ELDIM at Eurodisplay'1993 [6]. The Fourier optic is designed in order to convert angular field map into a planar one allowing very rapid measurements of the full viewing cone. Each light beam emitted by the sample surface is collected by the optics and refocus on a Fourier plane at a position proportional to the incidence and azimuth angles (cf. figure 1). This Fourier plane is reimaged on a CCD detector. The multispectral system EZContrastMS measures the full viewing angle up to 88° versus wavelength using to 31 band-pass filters regularly distributed in the visible range every 10nm [7].

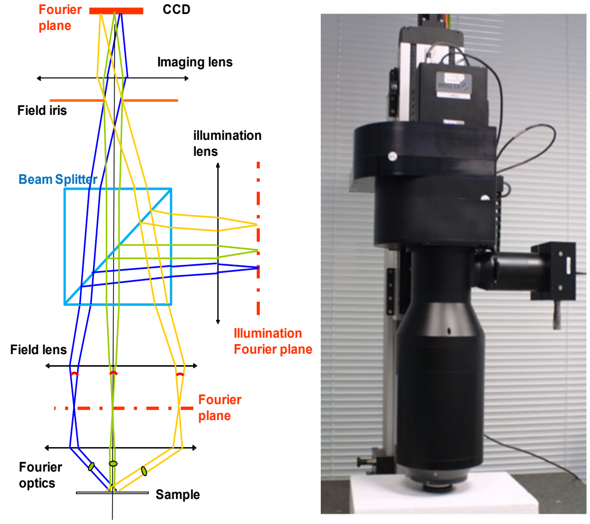


Figure 1. Schematic diagram and photograph of a Fourier system with beam splitter for internal illumination

Reflective measurements

For reflective measurements, it is necessary to illuminate the sample. It is made using a beam splitter and an additional optics that allows illumination at all the angles easily and accurately (cf. figure 1). An illumination lens reimages the first Fourier plane on an illumination plane. One point on this plane corresponds to one incidence on the surface of the sample. This instrument is classically used to perform spectral BRDF measurements on isotropic [8] or anisotropic surfaces [9].

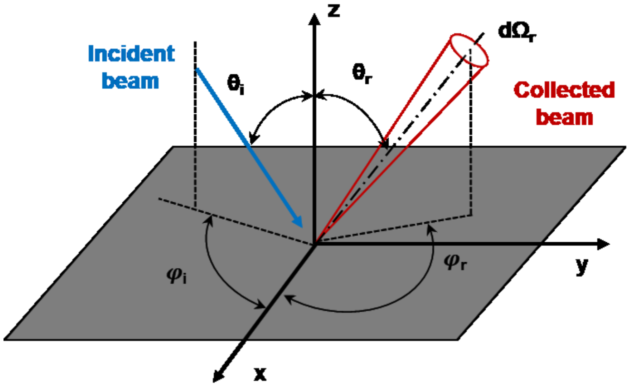


Figure 2. Definition of the spectral BRDF

Collimated beam illumination is realized with an optical fiber located on the illumination plane and moved to change the incidence and azimuth of the beam (cf. figure 1). The spectral BRDF depends on two incidence angles θ_i and φ_i, two observation angles θ_o and φ_o and the wavelength λ, as shown in figure 2. It is given by the following formula:

$$BRDF(\theta_i, \varphi_i, \theta_o, \varphi_o, \lambda) = \frac{L_s(\theta_o, \varphi_o, \lambda)}{E_i(\theta_i, \varphi_i, \lambda)}$$

The luminance L_s is directly given by the Fourier optics measurement on the sample. The irradiance of the incident beam E_i is evaluated by the integration a white reference measurement in the same illumination conditions.

$$E_i(\theta_i, \varphi_i, \lambda) = \iint_{2\pi} R_W(\theta_o, \lambda)\, L_W(\theta_o, \varphi_o, \lambda)\, cos(\theta_o)\, d\omega_o$$

$R_w\left(\theta_o, \lambda\right)$ *is the reflectance of the white reference sample used for the calibration. This sample is not perfectly Lambertian but it is not necessary because the integration is realized on the large angular aperture of the instrument that covers quasi completely the emissive space.*

Experimental results

In the following we discuss data obtained on two LCD displays with different liquid crystal technologies and different surface aspects. LCD1 is a Samsung UE22ES5400 TV using twisted nematic technology (TN) with a matte surface aspect. LCD2 is a Samsung UE32ES5500 TV using in plane switching technology (IPS) with a shiny surface aspect. The emissive and reflective measurements are made at the display center and we assume that there are fixed on all the display surface to perform the simulations.

Emissive properties of two LCD TVs

*Lightness measured in the CIE L*a*b* color space is reported for the two displays for different levels of green (from black to green color) and for all the angles (cf. figure 3). The viewing angle properties are strongly depending on the type of liquid crystal. The evolution of the lightness pattern of five green levels (0, 31, 91, 127 and 255), is defined by the rotation of the crystal cell that is very different in the two cases. The viewing angle is better for the LCD2 TV (IPS one). To perform ray tracing simulations the evolution of the red and blue pixels has also been measured in the same way as for the green pixels.*

Reflective properties of two LCD TVs

The reflective properties of the two LCDs are also very different as shown in figures 4 and 5 for a green wavelength of 550nm. BRDF measurements on LCD1 show a large specular peak that extend on more than 20 degrees for all the incident angles (cf. figure 4). It is why all reflections on this display are strongly blurred by the diffusion. On the contrary, BRDF measurements on LCD2 give a well-defined sharp specular peak characteristic of a mirror like surface (cf. figure 5). For the two displays, there is quasi no spectral dependence as expected for a glass surface. To perform ray tracing simulations, we have measured the spectral BRDF for 6 different incidence angles (10°, 20°, 30°, 40°, 50° and 60°°. The values in between are interpolated with the method discussed in reference [4].

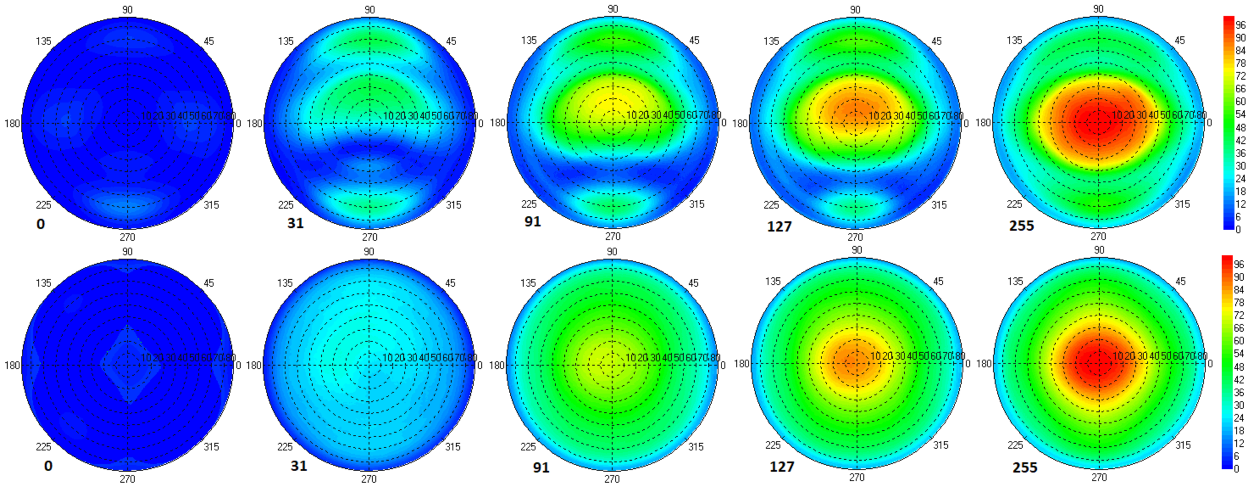


Figure 3. Lightness measured at different levels of the green color of LCD1 (top) and LCD2 (bottom)

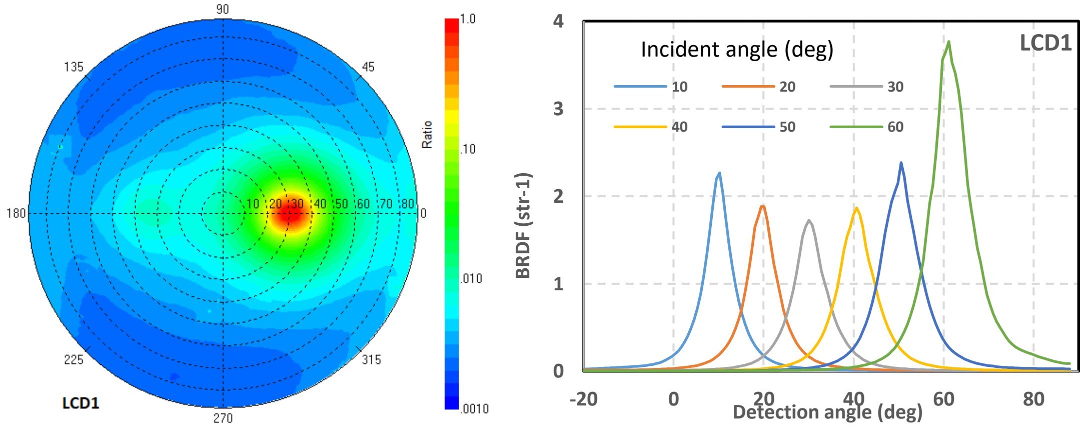


Figure 4. BRDF measured at 550nm on LCD1: angular diagram for 30° of incidence (left) and angle dependence in the incidence plane for 6 incidences (right) are reported.

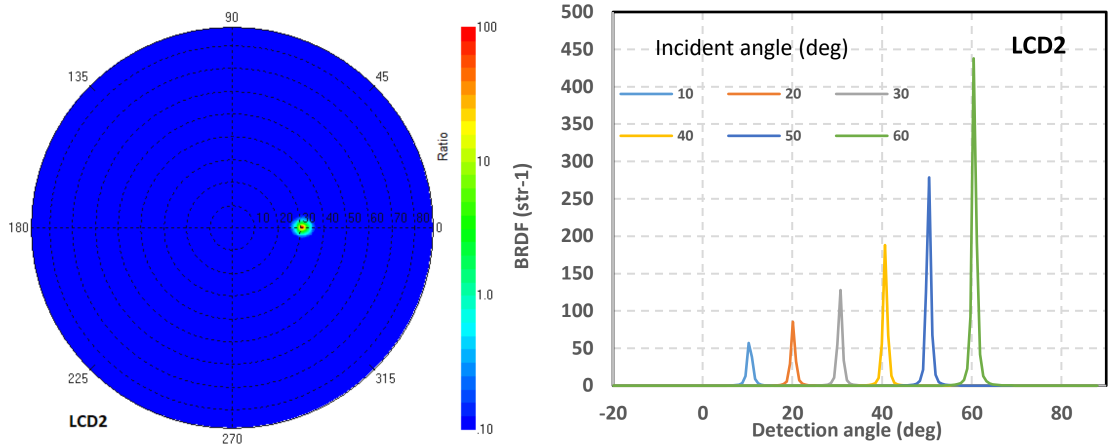


Figure 5. BRDF measured at 550nm on LCD2: angular diagram for 30° of incidence (left) and angle dependence in the incidence plane for 6 incidences (right) are reported.

Simulation results

Analytical simulation method:

We assume that reflective and emissive properties of the display can be separated. It is true except for very specific cases like reflective displays or electronic papers. Most of the displays found on the market can be taken into account with our simulation. The XYZ CIE emissive components are directly deduced from experimental data using geometric considerations. For the reflective properties, the illumination of each pixel for the different sources (punctual or diffused) can be evaluated and the reflective results in the direction of the observer deduced. For a given initial image, the computation is made for each pixel of the image and the aspect of the resulting image is obtained. A schematic diagram of the method is reported in figure 6. The computation of the emissive properties and reflective properties are realized separately. Color results are obtained by addition of the different XYZ contributions. The intensity of the parasitic sources can be adjusted during this last step of the computation. Consequently, the influence of the parasitic sources can be obtained rapidly and easily.

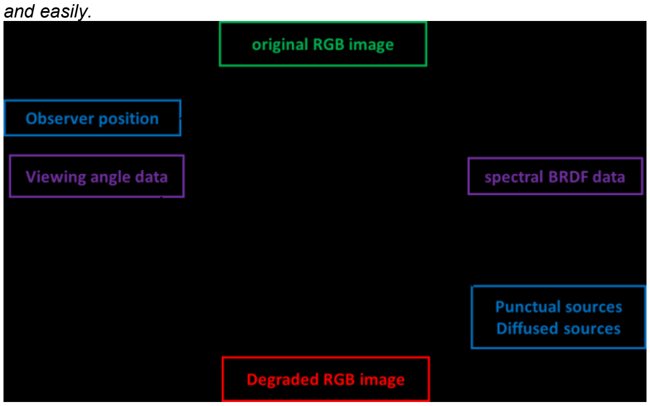


Figure 6. Schematic diagram of the analytical simulation method.

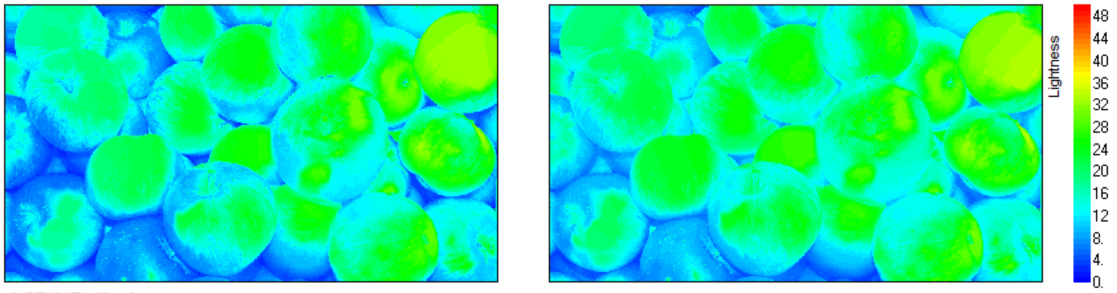
Analytical simulation of LCD1 and LCD2:

We have simulated the same color image on each LCD display (cf. figure 7). To enhance the effect of the emissive angular variations we have decided to fix the observer at 60° of the normal of the center of the display. If we take into account the display size and the observer distance, the simulation corresponds to a lateral angular variation of 51° to 65°.

Two simulations for each display are realized successively. The first one uses the emissive properties of each display (cf. figure 3) without any parasitic illumination. The second one includes and additional D65 collimated beam of 10000cd/m^2 at -60°to get the specular reflection in the center of the display. The reflection is simulated using the spectral BRDF of each display (cf. figures 4&5).

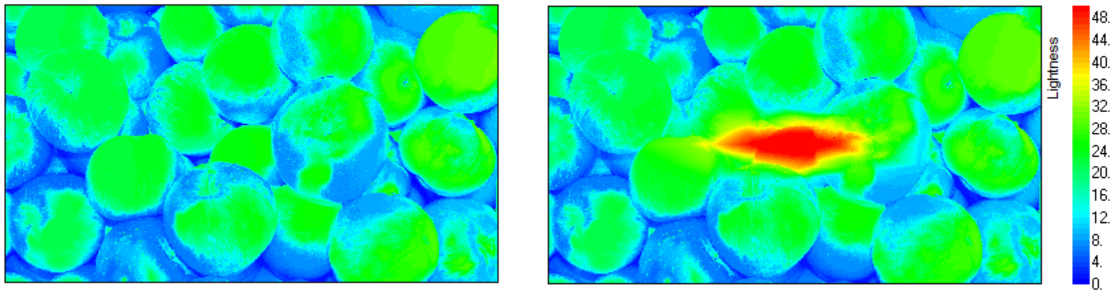
The lightness and chroma images for the two simulation conditions and the two displays are reported in figures 8 and 9. The reference white is selected at a D65 illuminant with 1000cd/m^2 luminance. The better emissive properties of LCD2 at high angle have clearly an impact on the aspect of the display. Both the lightness and chroma have a much better dynamic on the image of LCD2. The parasitic illumination has a very different impact on the two displays. On LCD1 the lightness is slightly increases on all the image because of the low gloss of this display (cf. figure 4). On the contrary, the specular reflection of the parasitic light beam is clearly visible in the center of the image and produces an important lightness increase because of the high gloss of the display surface (cf. figure 5). This lightness increase is followed by a strong chroma decrease on the specular reflection. The impact outside the specular peak is very small. On the contrary the impact of the parasitic light is sensitive but much smaller on the entire image for LCD1.

Figure 7. Color image used for the simulations.



LCD1 Emissive

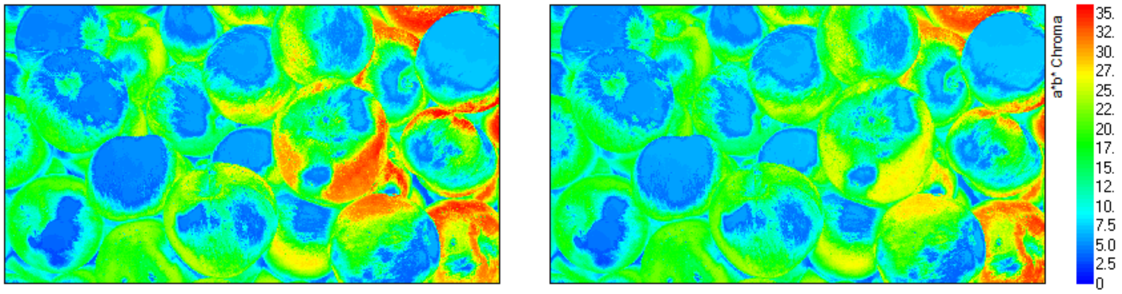
LCD1 Emissive + Specular



LCD2 Emissive

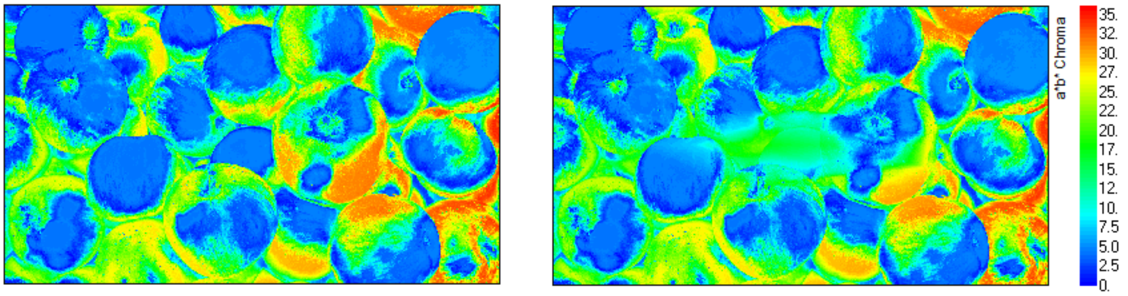
LCD2 Emissive + Specular

Figure 8. Simulated lightness of same color image displayed on LCD1 (top) and LCD2 (bottom) and observed at 60° without parasitic light (left) and with a D65 collimated beam at -60° of 10000cd/m^2 (right): white reference D65 at 1000cd/m^2.



LCD1 Emissive

LCD1 Emissive + Specular



LCD2 Emissive

LCD2 Emissive + Specular

Figure 9. Simulated chroma of same color image displayed on LCD1 (top) and LCD2 (bottom) and observed at 60° without parasitic light (left) and with a D65 collimated beam at -60° of 10000cd/m^2 (right): white reference D65 at 1000cd/m^2

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To understand better the impact of the parasitic light we have reported the lightness and chroma histograms of the images on LCD1 and LCD2 with and without parasitic light. There are reported in figure 10. In each case, the histogram of the image taking into account the emissive properties are reported in blue, and the one with additional parasitic light in red. The impact of the gamma scale at 60° that is strongly perturbated for LCD1 is clearly seen comparing the emissive histograms of the two displays. The parasitic light induces the shift of the histogram for LCD1 that affect all the image. On the contrary only a limited number of pixels is affected by the parasitic light for LCD2.

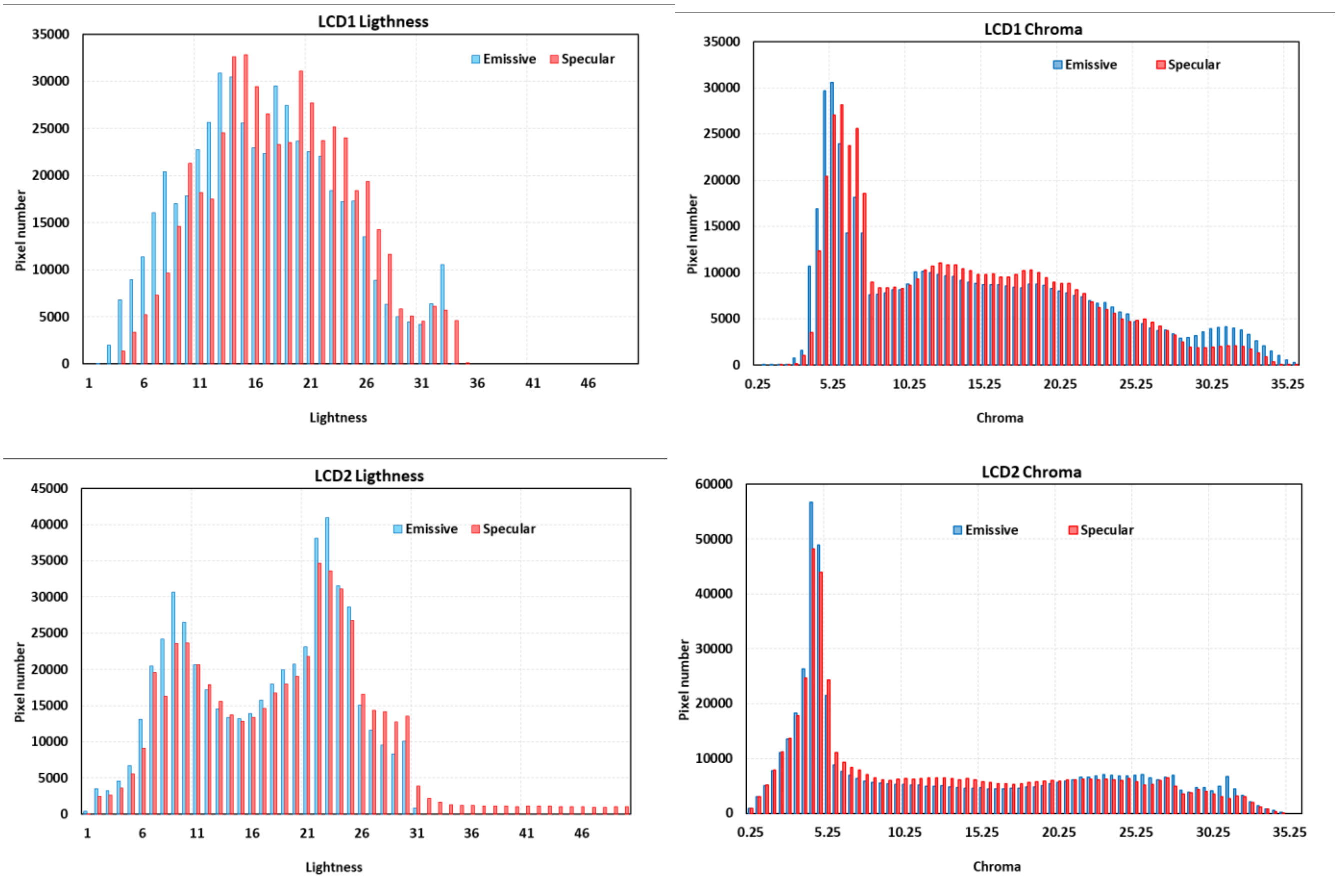

Figure 10. Pixel distribution of lightness (left) and chroma (right) simulated color image displayed on LCD1 (top) and LCD2 (bottom) and observed at 60° without parasitic light (bleu) and with a D65 collimated beam at -60° of 10000cd/m^2 (red): white reference D65 at 1000cd/m^2.

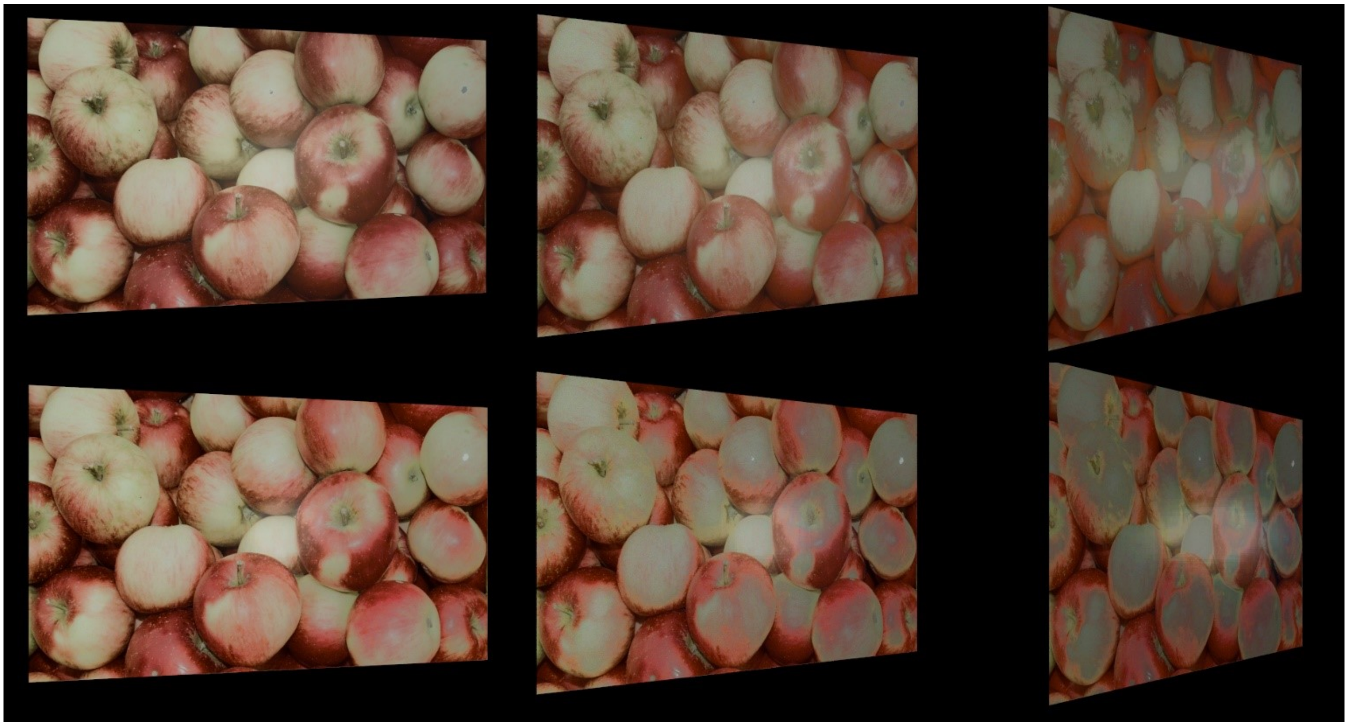

Figure 11. Ray tracing simulation of the same color image displayed on LCD1 (top) and LCD2 (bottom) displays at 20°(left), 40° (center) and 60° (right) incidences. Collimated source at the same angles in symmetric positions, are also included

Ray tracing simulation method:

Predicting the appearance of all types of object, including screens, necessarily implies physical simulation. Our main goal is to render reliable images of virtual scenes to help designers to take effective decisions related to appearance. Indeed the appearance of an object can only be evaluated in-situ, taking into account simultaneously the light, the shape, the matter and the point of view. Ray-tracing algorithms, in particular Path-tracing [10], make it possible to reproduce all the light phenomena involved in geometric optics including global illumination. This is formally expressed by the rendering equation:

$$L_r(x,\vec{\omega}_r) = L_e(x,\vec{\omega}_r) + \int_S \rho_{bd}(x,\vec{\omega}_i,\vec{\omega}_r).L_r(x',\vec{\omega}_r').G(x,x')dxdx'$$

where L is the luminance, ρ the total bidirectional reflectance function and G a differential form factor equal to 0 when the point x and x' are not visible to each others. Otherwise G is:

$$G(x,x') = \frac{\cos\theta_i \cos\theta_r'}{d^2}$$

A wide variety of rendering engines based on Ray-tracing algorithms exist, but most of them only perform RGB calculations and make use of theoretical models of material that can not account for real materials. This approach is well suited for illustration and visual effects (vfx) but does not permit to predict the real appearance of an object. With this in mind, UVR has developed Omen Render, a simulation software for Iso-Photographic rendering [11]. This software perform the render in spectral and polarized mode and is based on measurements. It means that all lights and materials data come from measurements ensuring the reality and feasibility of the scene. In the case of screens, the object is both reflective and emissive. The reflectance and emittance measurements from ELDIM were used to produce the images of the figure 11. In this scene, a virtual light source is positioned so that the specular reflection appears in the center of the screen for all the angles (cf. figure 12).

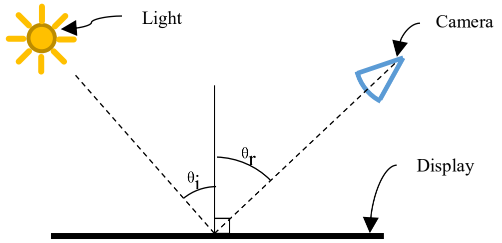

Figure 12. Schematic geometry of the 3D scene

The difference between the two screens appears very clearly in the simulations, in particular at grazing angles. In particular, we can see that the LCD2 shows a high contrast reversal when viewing on the side. These results are in agreement with the analytical simulations presented previously.

Conclusions

In this paper we have presented a method to characterize completely the reflective and emissive properties of a display making measurements with a Fourier optics viewing angle system. Emissive properties are measured for each primary color at different pixel levels. Spectral reflective properties are measured for different incidence angles for isotropic surfaces (generally LCDs) and different incidence and azimuth angles for anisotropic surfaces (generally OLEDs). Analytical simulations are useful to understand better the performances of the displays under parasitic illumination and to compare the performances of the displays in simple conditions.

We proposed also a new Computer Aided Design scheme based on the prediction of the appearance of screens in real environment. This approach is clearly effective to reduce the number of physical prototypes in many areas such as consumer electronics or automotive industry. The fast measurement of full spectral reflectance and emittance using Fourier optics EZContrast, device in combination with powerful physically based simulation by Omen Render, enables reliable images to be produced in real-life situations.

The intensity of the surface reflection is directly linked to the state of polarization of the light. In a future work we will propose to simulate the effect of polarization on the perception of light reflection on displays.

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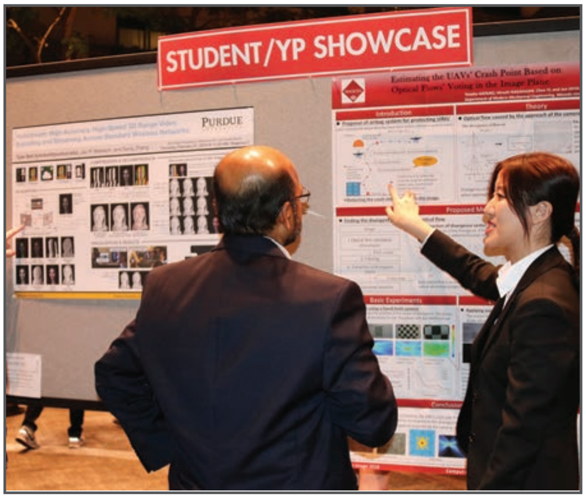
Author Biography

Pierre Boher earned an Engineer degree at ECP, “Ecole Centrale des Arts et Manufactures” in 1982. He obtained his Ph.D. in material sciences in 1984 and his ability to research management at “University Pierre et Marie Curie” in 1991. He worked in the French Philips Laboratories during nine years on the deposition and characterization of very thin films and multilayers. R&D manager at SOPRA between 1995 and 2002, he developed different metrology tools for non-destructive characterization mainly for microelectronics. He joined ELDIM as R&D manager in 2003.

Thomas Muller is an expert in simulation and virtual reality. He earned a Master degree in Software Engineering Science (MSES) at the University Toulouse Paul Sabatier France (1999) and he is actually writing his Ph.D thesis about iso-photographic rendering. He has pioneered techniques for simulating the appearance of car paint at Peugeot SA, Creativity and Innovation Lab. Thomas co-founded the companies On-Situ and United Visual Researchers.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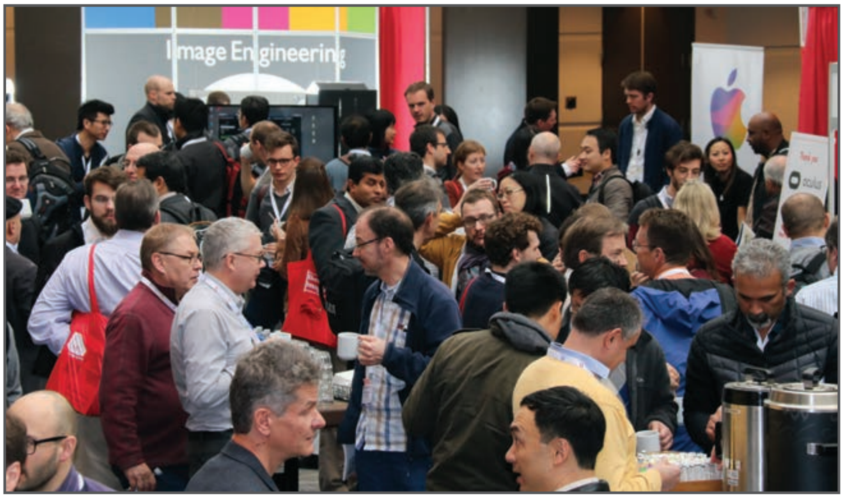
Image Engineering

My first working AR prototype
Today's platforms
Ubiquitous consumer AR
Optimis
this is
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