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FIRST RESULTS OF COLORIMETRIC MATERIAL CHARACTERIZATION STUDY BETWEEN *IEN* AND *INMETRO* NATIONAL STANDARDIZING INSTITUTES

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Abstract: As part of the cooperation between two National Standardizing Institutes, *Istituto Elettrotecnico Nazionale "Galileo Ferraris"* (IEN) and *National Institute of Metrology, Standardization and Industrial Quality* (Inmetro), a colorimetric material characterization study has been initiated in 1999. With the main purpose of check the preliminary performance of the reference system used in the Radiometry Laboratory of Inmetro, four color samples were measured. On the first stage, the characterization of the samples was done at the IEN using a special goniophotometer, which doesn't need calibration of the detector and use an absolute measurement technique. Spectral measurements were made on typical configurations of lighting and reflecting conditions for colorimetric characterization of materials, 0/45 and 45/0. Photometric measurements were carried out by using a V(λ) filter in front of the detector and an illuminant A source at incident angles 0° and 45°. In the colorimetric and photometric cases, the results of measurements were respectively the three chromaticity coordinates calculated by the reflection factor (ρ), and the luminance associated to each direction. On the second and actual stage, measurements have been realized using an experimental set up for spectral reflectance and transmittance measurements at Inmetro. This work presents the results of measurements made by IEN.

Keywords: colorimetric, material, characterization, goniophotometer.

1. INTRODUCTION

A reference system for colorimetric material characterization with high accuracy has been developed by the *National Institute of Metrology, Standardization and Industrial Quality* Radiometry Laboratory. This reference instrument is designed to perform spectral reflectance and transmittance measurements of non-fluorescent samples. It has sufficient flexibility to accurately measure spectral and luminous quantities at all possible combination of illumination and viewing angles, for lighting engineering applications, like accurate image rendering and to provide calibration services for standard conditions (incident angle 0°/observing angle 45° or 0/45, 45/0, 0/d and d/0) industrial color etalons.

On november 1999, as part of a cooperation between *Istituto Elettrotecnico Nazionale "Galileo Ferraris"* (IEN) and *National Institute of Metrology, Standardization and Industrial Quality* (Inmetro) a colorimetric material characterization study has been initiated. This first study was aimed at characterizing the performance of the color reference system of Inmetro. The instrument utilized at IEN for the photometric, colorimetric and spectra-radiometric material characterization was a special goniophotometer, which doesn't need a calibration of the detector in SI units and use an absolute measurement technique.

Four color samples, white, red, yellow green and purple color standards supplied by Minolta Corporation, were measured during this first part of the intercomparison study. At present, measurements have been realized using the reference experimental set up for spectral reflectance and transmittance measurements mounted at Inmetro. This work presents the results of measurements made by IEN.

2. THE IEN GONIOPHOTOMETER

The IEN goniophotometer [1] consisted essentially of a fixed source, a 4 m long optical bench supporting at one end a detector and rotating at its center around the vertical axis of the instrument (Figure 1). On this same axis a set up was mounted, consisting of a cradle, on which the sample was placed through a three axes positioning system and a rotator. Reflection measurements could be performed over the full range of lighting and observing angles (some dead angles due to the sample dimension exist in transmission directions and due to the detector dimension in the reflection directions). The cradle could also be lowered for permitting the measurement of the lighting beam directly through the detector, in its calibration phase.

The source utilized was a tungsten halogen lamp supplied by a stabilized power supply at 7,754 A corresponding to color temperature of 2856 K and realizing the CIE standard illuminant A [2]. To stabilize the source two quantities were continuously under tested: its color temperature and its luminance. Moreover, the power supply circuit of the lamp was automatically controlled by the output signal of a silicon detector head, illuminated by the source light linked with an optical fiber. Between the optical fiber output and the silicon detector, a turret could rotate

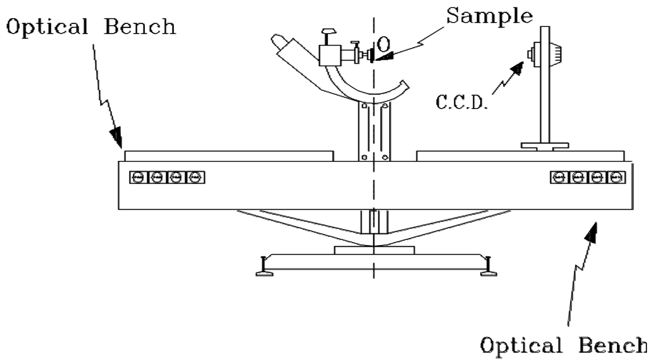

Fig. 1. IEN goniophotometer.

four different filters: one black obstructing the signal to avoid detector fatiguing; one reproducing the V(λ) color matching function of CIE, to measure the source luminance; one blue, centred on 430 nm and one red, centred on 990 nm (for both the full width half maximum bandwidth was 10 nm), to control the source color temperature. According to Rossi and Sarotto [3], using the V(λ) filter, the source luminance was stabilized better than 0,2%, while measurement of color temperature of incandescent sources using red to blue ratio evaluation was with an accuracy of 10 K.

In this study, since there were not requested the highest metrological performances, but we were interested mainly in the directional properties of the samples, the measurements were done using the "Photo Research Spectra-Photo-Colorimeter Model PR–1980BX-SC" instead of the original CCD detector, obtaining:

- luminance values of the source and reflected by the samples with a resolution of 0,1 cd m^{-2} and a relative uncertainty of 2%;
- color temperature of the source (that must be the CIE standard illuminant A) with a resolution of 1 K and an uncertainty of ±10 K;
- trichromatic coordinates of the samples.

During the measurements the solid angle of the incident beam and of view was equivalent to a plane angle of less then 1°.

3. CHARACTERIZATION OF COLOR SAMPLES

3.1 Goniometric measurements

The photometric, colorimetric and spectra-radiometric sample characterization was done illuminating it and measuring the fraction of energy that was reflected. A complete characterization needs the determination of these fractions for each geometrical condition of incidence and diffusion. In the photometric and colorimetric cases, the results of measurements were respectively the luminance coefficient or the three chromaticity coordinates associated to each direction [2]. In the spectra-radiometric case, the analysis involved the spectrum of the reflected radiation for each geometrical configuration.

Different physical quantities have been introduced for the material characterization. Their value depends on the measurement geometry, but also on other factors here not considered: the polarisation of incident radiation, the value of the solid angles of incidence and observation, etc…

Photometric measurements were carried out by using a V(λ) filter on incident angles 0° and 45°. Observation angles varied from 8° to 60° in the same plane of incidence ($\varphi_1 = \varphi_2$ or $\varphi_1 = \varphi_2 + 180°$).

The luminance coefficient or BRDF [2], is defined as:

$$BRDF(\varepsilon_1,\varphi_1;\varepsilon_2,\varphi_2) = \frac{dL_2(\varepsilon_2,\varphi_2)}{dE_1(\varepsilon_1,\varphi_1)} = \frac{dL_2(\varepsilon_2,\varphi_2)}{dL_1(\varepsilon_1,\varphi_1)\cdot\cos\varepsilon_1\cdot d\omega_1} \quad (1)$$

where:

- BRDF (Bi-directional Reflectance Distribution Function) is the luminance coefficient: its unit is [sr^{-1}];
- E_1 is the incident beam illuminance on the sample;
- L_1 is the luminance of the incident beam;
- $d\omega_1$ is the incident beam solid angle;
- L_2 is the sample luminance in the observation direction;
- the angles ($\varepsilon_1,\varphi_1;\varepsilon_2,\varphi_2$) are self evident in Figure 2 where the reflection geometry is represented;
- in Figure 2 (xsn, ysn, zsn) are the axes for the sample reference system with zsn axis along the sample normal.

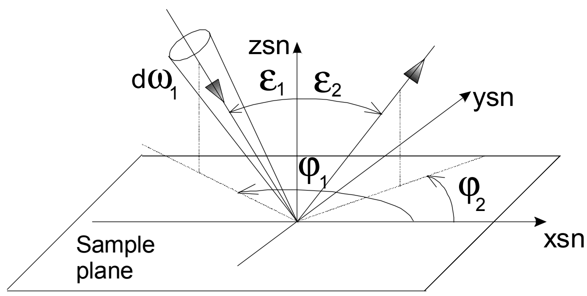

Fig. 2. Reference angular system for incident and reflected light.

The luminance factor is defined as:

$$\beta(\varepsilon_1,\varphi_1;\varepsilon_2,\varphi_2) = \frac{L_2}{L_{2,W}} \quad (2)$$

where:

- L_2 is the sample reflected luminance in a certain measurement configuration geometry ($\varepsilon_1,\varphi_1;\varepsilon_2,\varphi_2$);
- $L_{2,W}$ is the perfect diffuser [2] reflected luminance in the same measurement configuration geometry.

In this part of the experiment, the behaviour in reflection of the samples was the main parameter to quantify, therefore a simply measurement procedure was followed. The white sample, at normal incidence and at quasi-normal diffusion (to not acquire the regular reflection) was considered as a perfect reflecting diffuser, an ideal uniform diffuser with a reflectance equal to unity, the luminance factor was calculated following the equation 2 for each measurement geometry. Results are shown in Figures 3 and 4 for the two incidence angles considered. For observation angles greater than 15° from the regular reflection the behaviour of the sample is quite constant and, in this range, the alignment constraints of the sample for calibration applications are relatively weak.

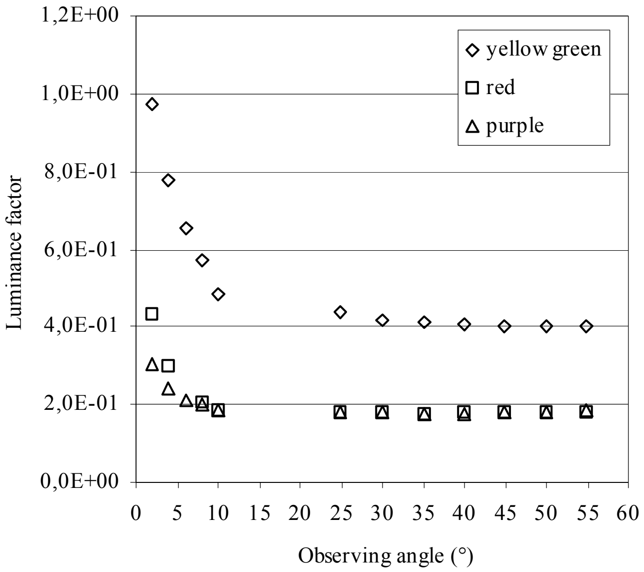

Fig. 3. Luminance factor for illuminating angle 0° (The dead zone due to detector dimension is at 0°).

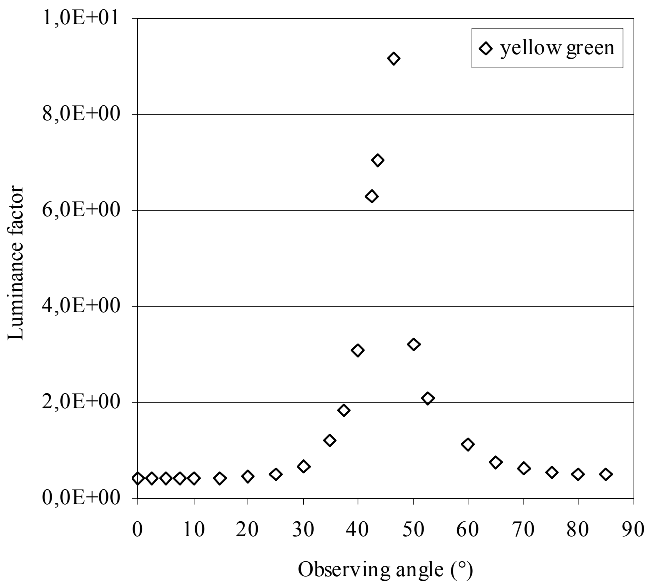

Fig. 4. Luminance factor for illuminating angle 45° (The dead zone due to detector dimensions is at 45°).

3.2 Colorimetric measurements

Spectral measurements at 10 nm of wavelength interval were made on typical configurations of lighting and reflecting conditions for colorimetric characterization of materials, 0/45 (incident angle 0°/observing angle 45°) and 45/0. The reflection factor:

$$\rho = \frac{\Phi_2}{\Phi_1} \tag{3}$$

where:

- Φ_2 is the reflected flux by the sample when it is lighted in a certain geometrical condition;
- Φ_1 is the incident flux

was calculated for each standard geometry. Chromaticity coordinates were calculated for CIE standard illuminants A and D_{65} using the following equations (the effective integral limits were 380-780 nm due to instrument limitations):

$$X = \int_{360nm}^{830nm} S_\lambda \bar{x}(\lambda)\rho(\lambda)d\lambda \qquad x = \frac{X}{X+Y+Z} \tag{4.a}$$

$$Y = \int_{360nm}^{830nm} S_\lambda \bar{y}(\lambda)\rho(\lambda)d\lambda \qquad y = \frac{Y}{X+Y+Z} \tag{4.b}$$

$$Z = \int_{360nm}^{830nm} S_\lambda \bar{z}(\lambda)\rho(\lambda)d\lambda \qquad z = \frac{Z}{X+Y+Z} \tag{4.c}$$

where:

- S_λ is the spectral power distribution of the incident radiation;
- $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ are the CIE 1931 color-matching functions;
- X, Y, Z are the CIE trichromatic values;
- x, y, z are the CIE chromaticity coordinates.

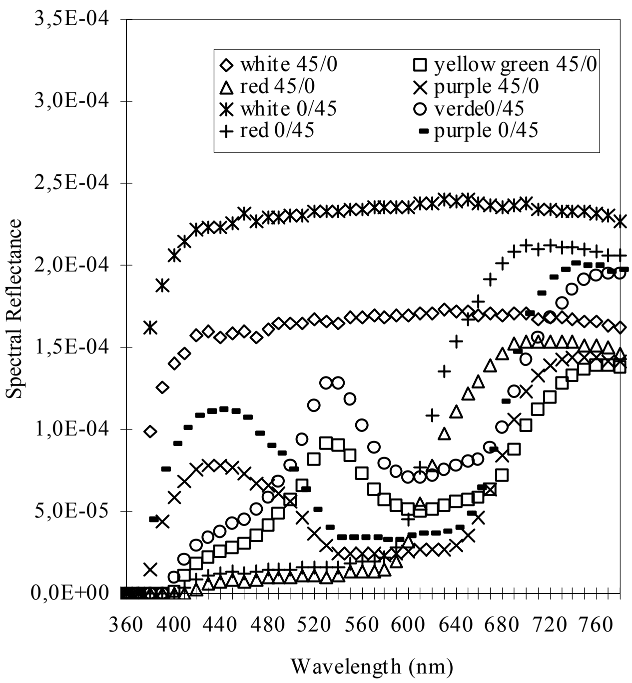

Fig. 5. Spectral reflectance for color samples in 45/0 and 0/45 geometries.

CIE chromaticity coordinates calculated and measured by PR-1980BX-SC are shown in the following Tables 1 and 2. The comparison between measured and calculated values can be done only for illuminant A. Differences depend on the sample color and could be due to several causes. The main point to evaluate is discrepances between the source spectra and illuminant A (i.e. the influence of the optical collimating system) and a non-constant spectra-correction uncertainty with wavelength.

Table 1. CIE chromaticity coordinates for color samples in 45/0 geometry

45/0 geometry		Measured			Calculated		
sample	Illum.	x	y	z	x	y	z
white	A	0,4543	0,4132	0,1325	0,4527	0,4096	0,1377
	D_{65}				0,3187	0,3355	0,3457
yellow green	A	0,4443	0,4705	0,0852	0,4438	0,4681	0,0881
	D_{65}				0,3343	0,4424	0,2233
red	A	0,6260	0,3438	0,0303	0,6262	0,3425	0,0312
	D_{65}				0,5341	0,3433	0,1226
purple	A	0,3878	0,3378	0,2743	0,3844	0,3322	0,2834
	D_{65}				0,2387	0,2167	0,5446

Table 2. CIE chromaticity coordinates for color samples in 0/45 geometry

0/45 geometry		Measured			Calculated		
sample	Illum.	x	y	z	x	y	z
white	A	0,4527	0,4122	0,1351	0,4511	0,4085	0,1404
	D_{65}				0,3166	0,3328	0,3506
yellow green	A	0,4427	0,4691	0,0882	0,4422	0,4666	0,0912
	D_{65}				0,3315	0,4373	0,2312
red	A	0,6204	0,3438	0,0359	0,6205	0,3425	0,0371
	D_{65}				0,5190	0,3365	0,1445
purple	A	0,3848	0,3356	0,2796	0,3813	0,3298	0,2889
	D_{65}				0,2366	0,2133	0,5501

Only with the yellow green sample some particular spectral measurements were carried out at polar angle value equal to 10° (ε_2) on the regular and retroreflective plane, instead of the usual 0° of the 45/0 configuration. These results are shown in Figure 6 compared to the result at 45/0. This measurement was useful to verify the geometrical variation in the reflected spectra. The main changes are in the blue region, but the influence of the instrument specification are very important because, in this part of the spectra, the energy of the source is lower than in the red region and the sensitivity of the detector is lower so the dynamic of the instrument play a key role.

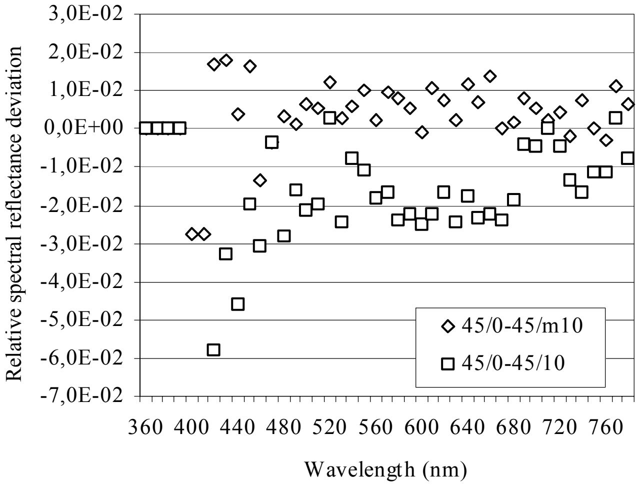

Fig. 6. Spectral reflectance deviation for yellow green sample on the specular plane (45/10) and catadiotric plane (45/m10) relative to the 45/0 geometry.

4. CONCLUSIONS

To check the performance of the reference system of Inmetro, four color samples were characterized directly on the special goniophotometer of IEN. Efforts have been done in the direction of establish an high accuracy measurement system on the Radiometry Laboratory. Some previous results using this experimental system had already been obtained with good agreement using reflectance standards such as One Russian Opal, one matt black tile and one glossy black tile, and color standards, one set of glossy and one set of matt ceramic tiles. Results referred to the second and actual stage will be presented in the future as soon as measurements at Inmetro finished. This qualitative comparison of regular reflectance and colorimetric measurements that has been carried out between the standardizing Institutes of Brazil (Inmetro) and Italy (IEN) indicate the ability of Inmetro to measure reflectance.

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