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WHAT IS THE TRUE WIDTH AND HEIGHT OF THE SPECULAR PEAK ACCORDING THE LEVEL OF GLOSS?

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Abstract

When evaluating the gloss of a surface, observers always look in and around the specular direction. Thus, the specular peak contains information connected with gloss. In order to progress in the comprehension and measurement of gloss, it could be therefore useful to study it. But this peak is narrow and not all measurement devices have the proper optical settings to access the peak. Using a dedicated goniospectrophotometer, we have measured the specular peak of a commercial gloss scale with samples varying from matt to full glossy. From these traceable and metrological measurements, we clarified the settings requested to access a reliable BRDF of the surface in the specular direction, according to its gloss level measured with a classical glossmeter. For gloss values higher than 60 GU, the angular resolution of the measurement setup should be lower than 0.05° to ensure proper BRDF measurement.

Keywords: goniospectrophotometry, gloss, specular peak, BRDF

1 Introduction

When evaluating the gloss of a surface, observers always look in and around the specular direction. For this reason, we assume that gloss takes its origin in the specular peak of the BRDF of the surface [Leloup, 2010]. For a glossy surface, the BRDF shows a sharp and high peak in the specular, where for matt surfaces, the peak, if it exists, is spread and small. For mid-gloss surfaces, the peak has an intermediate size and width [Obein, 2007]. In order to progress in the comprehension of gloss and to propose new ways for its measurement, it is necessary to measure the specular peak.

But the access of the specular peak is not as straight forward as it may seem. As a matter of fact, the measurement equation of the BRDF is given by [Nicodemus, 1978]:

$$f\big(\theta_\mathbf{I}, \varphi_\mathbf{I}, \theta_\mathbf{R}, \varphi_\mathbf{R},\, \Omega_\mathbf{R}, \lambda,\, \sigma\big) = \frac{\phi_\mathbf{R}(\theta_\mathbf{I},\varphi_\mathbf{I},\theta_\mathbf{R},\varphi_\mathbf{R},\,\Omega_\mathbf{R},\lambda,\sigma)}{\phi_\mathbf{I}(\theta_\mathbf{I},\varphi_\mathbf{I},\lambda,\sigma)} \cdot \frac{1}{\Omega_\mathbf{R}\,|\cos\theta_\mathbf{R}|} \tag{1}$$

where

    $\theta_\mathbf{I}$, $\varphi_\mathbf{I}$, are respectively the zenith and azimuth angles of the direction of illumination
    $\theta_\mathbf{R}$, $\varphi_\mathbf{R}$, are respectively the zenith and azimuth angles of the direction of observation
    $\phi_\mathbf{I}$, $\phi_\mathbf{R}$, are respectively the incident and reflected fluxes
    $\Omega_\mathbf{R}$, is the solid angle subtended by the receiver aperture and pointing at the sample origin
    σ, is the polarisation of the light
    λ, is the wavelength

In order to get a valid measurement, the solid angles $\Omega_\mathbf{I}$ and $\Omega_\mathbf{R}$, that are defined by the measurement setup optical design, must be negligible according to the angular variations of the BRDF of the sample. This is the case in most of the measurement situation, except when measuring the specular peak of glossy samples.

As a matter of fact, for glossy samples, the specular peak can be narrow and reach a FWHM of 0,5° at the top of the gloss scale. Valid assessment of this peak request then a measurement setup that will have an illumination and collection solid angles small enough in front of these variations, so with a half aperture angle lower than 0,02°. If measured with a larger aperture,

the result will not reflect the specular peak, but the convolution between the peak and the apparatus function of the goniospectrophotometer [Obein, 2015].
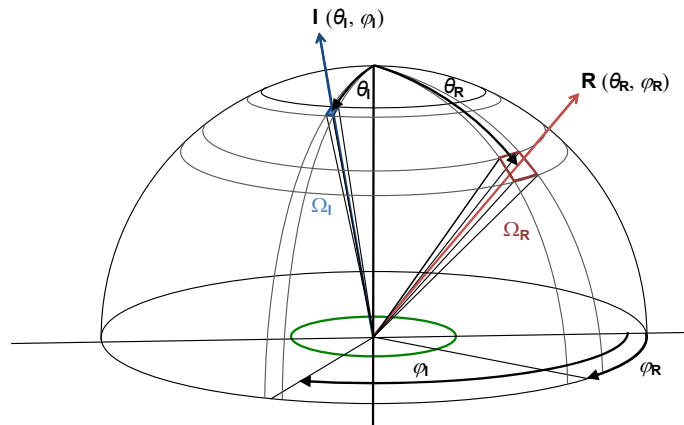

Figure 1 – Notations used for the measurement of the BRDF. The sample is illuminated along the direction I and the radiance is measured along the direction R. For valid measurements, solid angles Ω_I and Ω_R must be small according to the variations of the BRDF.

In consequence, if classical spectrophotometers can provide a trustable measurement of the BRDF for a satin surface, most of them will be incapable to resolve the specular peak of high gloss surfaces.

It is to avoid misinterpretations of results carried on with non-adapted spectrophotometer on glossy surface that this study has been carried out. Our objective is to access the specular peak of a set of samples, ranging from very matt to very glossy, with a metrological goniospectrophotometer optimized to perform this type of measurements, and then to extract from the measurements the heights and widths of the specular peaks.

2 Material and method

2.1 Samples

The study has been done on the commercial gloss scale provided by NCS. We used the black samples in order to focus on the specular peak only and avoid additional optical effect coming from the body diffusion. The 7 samples are made from coated paper. The 60° specular gloss of the sample set ranges between 2 and 95 gloss units (cf. Table 1).

Table 1 - Nominal values of 60° specular gloss index of the sample sets.

Sample	#1	#2	#3	#4	#5	#6	#7
60° specular gloss (GU)	2	6	12	30	50	75	95

2.2 Measurement device

We used our Conoscopic Device for Optical Reflectometry (ConDOR) [Ouarets, 2013]. ConDOR is a goniospectrophotometer composed of a mobile illumination system embedded on a 2 m diameter ring, a 6-axis robot as sample holder and an immobile detection (figure 2).
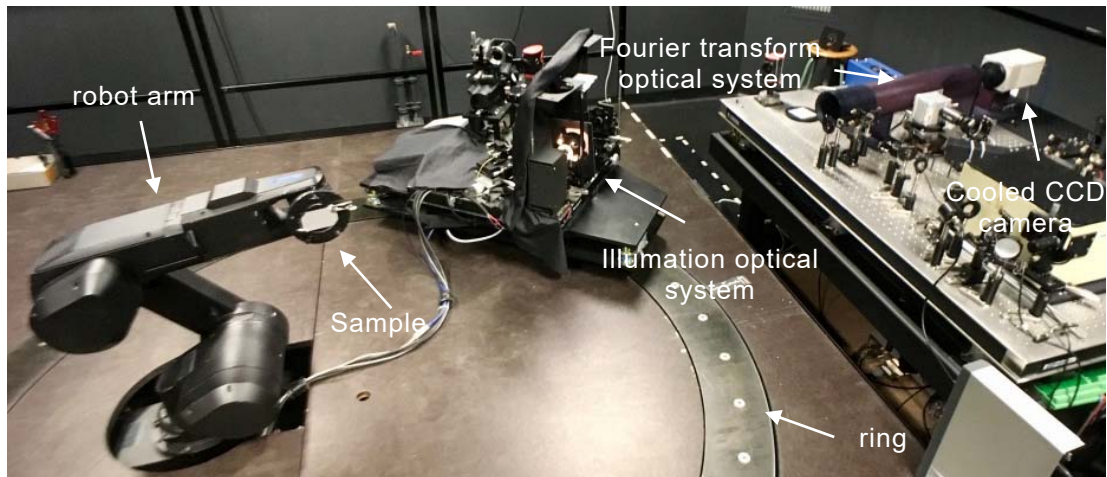
Figure 2 – Overview of ConDOR with its main components.

The robot arm provides 3 rotations. The ring provides a fourth one. Thus, all angular configurations for the illumination and observation are accessible with this setup.

The illumination part is made of a 200 W QTH lamp and an optical system that allows to illuminate the sample with a collimated light beam (figure 3). The filament is imaged on a black pinhole, placed behind a piece of sanded glass that plays the role of diffuser. The pinhole is set at the focal point of an achromatic doublet f = 400 mm. As gloss is not a spectral quantity, we don't control the wavelength in this setup. We use a $V(\lambda)$ filter to work with photometric quantities. After the doublet, the light beam is assumed to be collimated, with a divergence angle given by the ratio of the diameter of the pinhole by the focal length of the doublet. The shape of the beam is given by a circular diaphragm with a diameter of 10 mm.
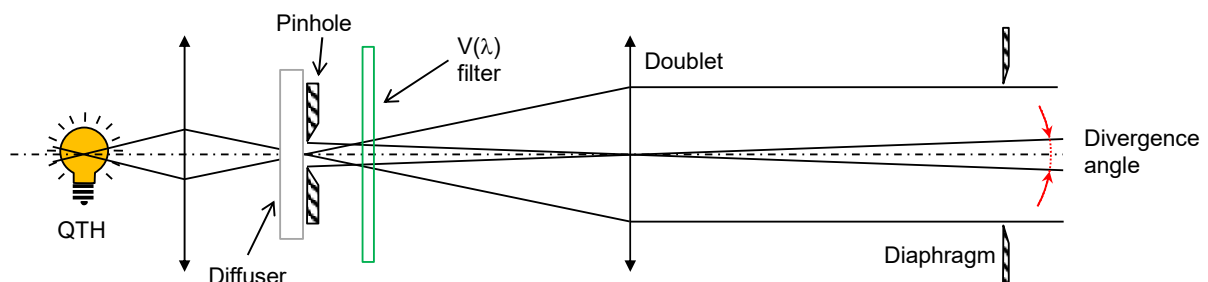

Figure 3 – Optical scheme of the illumination part

In this experiment, we used 3 different pinholes according to the level of gloss of the sample (Table 2).

Table 2 – Pinhole diameter and corresponding divergence

Pinhole diameter [µm]	Divergence [°]	$Gloss_{60°}$ range [gu]
1000	0,143	< 60
400	0,057	60 – 90
200	0,028	> 90

The detection is composed of a cooled CCD camera placed behind a Fourier optic-based system. This system has been successfully implemented for BRDF measurements by Eldim in the 90s [Leroux, 1993]. Our detection has been developed in collaboration with Eldim.

The optical system plays the role of a simple lens. Every light beam reflected from the sample along a given direction is focused at a unique position in the focal plane of the system, that

depends of the zenithal and azimuth angles of the beam. The luminance repartition in the focal plane is recorded with the CCD sensor and returns the angular characteristics of the light reflected by the sample (figure 4).

The system looks through a field of ±1°. The luminance is recorded using a high sensitivity cooled CCD camera (Hamamatsu ORCA II). The sensor is a matrix of 512 x 512 pixels. The combination of both water and Peltier cooling maintains it at a working temperature of -70 °C. The quantum efficacy of the CCD is optimized for the visible while a 16 bits A/D converter generates a high dynamic range.
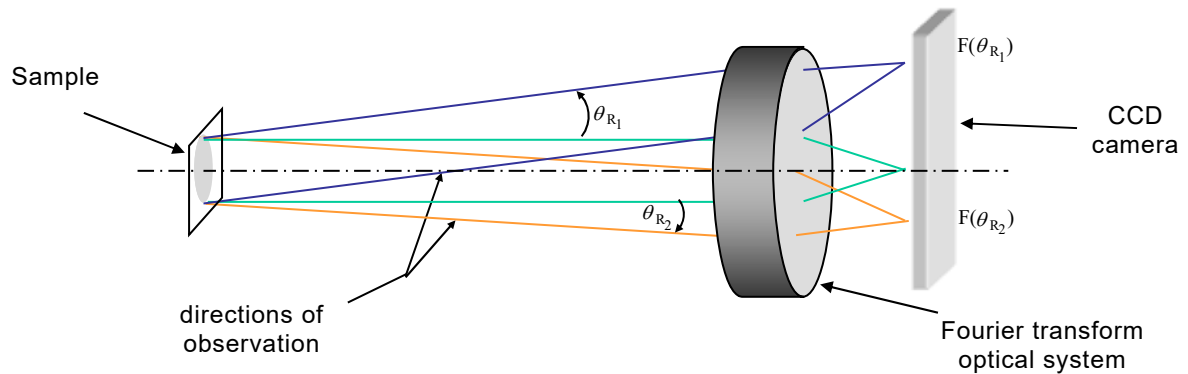

Figure 4 – Principle of the detection based on the Fourier optic: All the light reflected in a given is focused in one point at the focal plane of the optical system. The cartesian coordinates [x_R,y_R] of the point are related to the zenith θ_R and azimuth φ_R. The luminance at this point is recorded on a 512 $\times$ 512 pixels CCD camera.

The full metrological characterization of ConDOR's detection includes corrections of flat field, flux non-linearity, exposure time non linearity and optical noise. Corrections are made pixel per pixel. Traceability is established using a calibrated white diffuser [Ged, 2017].

From the settings described above, the solid angle of the detection Ω_R is defined by the angular resolution of the Fourier system, that is the full angular field (±1°) divided by the number of pixels (512). It gives 2°/512 = 0,004°. The solid angle of illumination Ω_I is defined by the divergence of the incident beam and depends thus upon the diameter of the pinhole (table 3). In our setup, this is Ω_I that limits the angular resolution of our measurement.

3 Results

The 7 samples of the NCS gloss scale have been measured with ConDOR set up. For each sample, the zenith angle of illumination was θ_I = 30°. The azimuth was φ_I = 180°. The BRDF is recorded in the plane of incidence.

Sample NCS1 is black and full matt. Its specular gloss at 60° is 2 gu. For this sample, no specular peak has been observed. The result is not presented in this paper.

For the 6 other samples, the cut of the specular peak in the plane of incidence is shown on Figure 5.
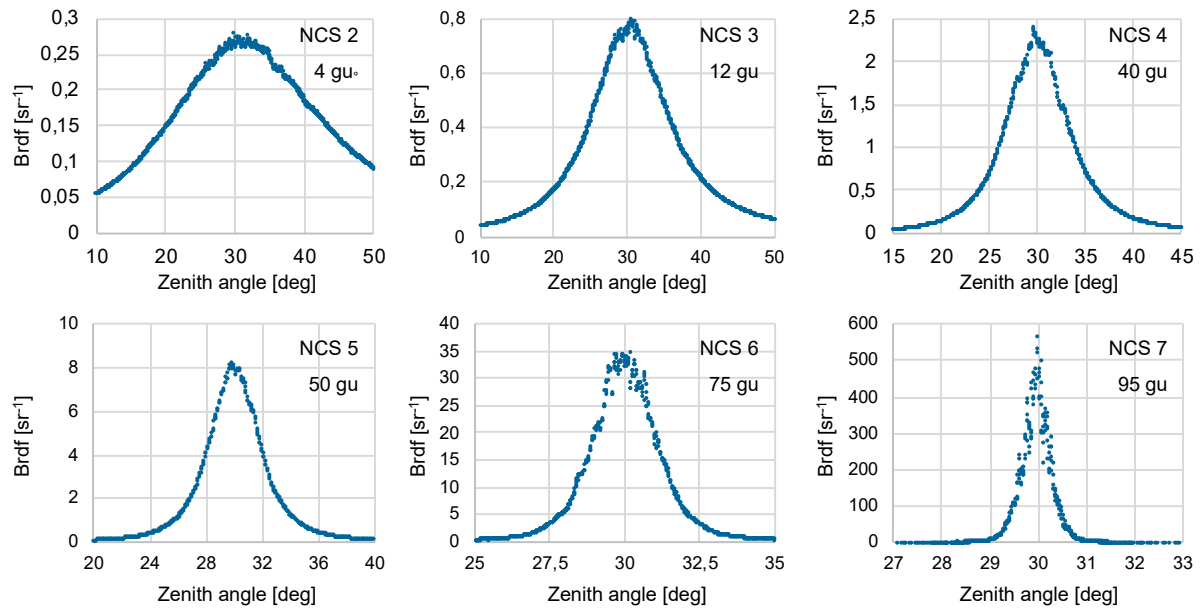
Figure 5 – Cut of the specular peak in the plane of incidence for the 6 samples of NCS black gloss scale. Name of samples is on the graphs. Zenith of incidence is 30°.

From these measurements, the value of the BRDF in the specular direction, and the full width at half maximum is computed, using Lorentzian model for the interpolation. The numerical values are summarized in table 3.

Table 3 – Summarize of the numerical values for the 6 specular peaks

Sample	Specular Gloss at 60° [gu]	Brdf max [sr⁻¹]	FWHM [deg]	Measurement Resolution [deg]
NCS2	6	0,266	25,9	0,15
NCS3	12	0,771	12,2	0,15
NCS4	30	2,22	7,3	0,15
NCS5	50	7,82	4,1	0,15
NCS6	75	32,2	2,36	0,06
NCS7	95	428	0,49	0,03

The angular resolution has been kept small enough to ensure that the apparatus function of our equipment doesn't modify the samples BRDF. These values can thus be considered has a trustable indicator of the characteristic of the specular peak for different levels of gloss.

4 Discussion

As we all know, when the gloss of the sample increases, the width of the specular peak decrease and the height of the peak increases. Nevertheless, it is important to notice that these values become quickly small and are often smaller than the user think.

We can notice that, for the NCS samples, the height and the width follow roughly an exponential law when plotted according to the value of the glossmeter (figure 6).
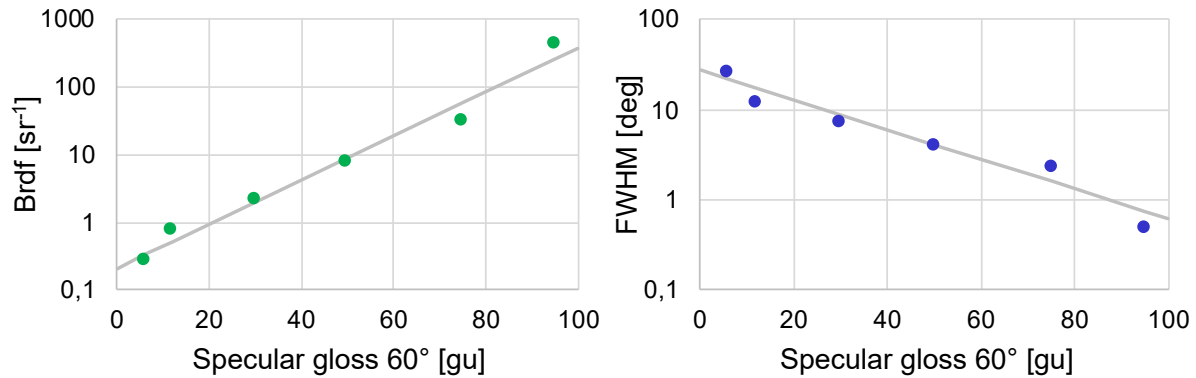
Figure 6 – Report of the height (left) and the width (right) of the specular peak according to the specular gloss at 60°. The evolution can be modelled by an exponential function

If we assume that, in order to keep an error below 5% in the measurement of the width of the peak, we must have an angular resolution at least 20 times smaller than the real width of the peak, then it is possible to provide recommendations on the solid angle of detection and on dynamic requested according to the level of gloss. These recommendations are extracted from the exponential model adjusted on the data as shown in figure 6, and summarize in table 4

Table 4 – Summarize of the recommended value on the solid angle of detection and for dynamic requested according to the level of gloss

Designation	Specular Gloss $_{60°}$ [gu]	Brdf dynamic [decade]	Max ½ angle detection [deg]	Max solid angle detection [µsr]
Full Matt	< 5	2	1,5	2154
Matt	5 < G <10	2	1,0	957
Semi-matt	10 < G <20	2	0,66	425
Satin	20 < G <40	3	0,33	106
Semi-Gloss	40 < G <60	4	0,15	21,5
Gloss	60 < G <90	5	0,05	2,39
Full Gloss	90 < G	5	0,03	0,86

5 Conclusion

When evaluating the gloss of a surface, observers always look in and around the specular direction. Thus, the specular peak contains information connected with gloss. In order to progress in the comprehension and measurement of gloss, it could be therefore useful to study the shape and the size of the specular peak. But this peak is narrow and not all measurement devices have the proper optical settings to access the peak. Using a dedicated goniospectrophotometer, we have measured the specular peak of a commercial gloss scale with samples varying from matt to full glossy. From these traceable and metrological measurements, we can recommend the settings requested to access a reliable BRDF of the surface in the specular direction, according to its gloss level measurement measured with a classical glossmeter. For gloss values higher than 60 GU, the angular resolution should be lower than 0.05°.

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