Recommendation for finite intervals in BRDF measurements of glossy samples

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Recommendations on the finite intervals of irradiation and collection solid angles for measuring the bidirectional reflectance distribution function (BRDF) of highly glossy samples, close to their specular direction, are derived from high angular resolution measures. These measures were done with the conoscopic system at the *Conservatoire National des Arts et Métiers*, CNAM, specially designed for measuring gloss. An equation was derived from the data to estimate the systematic relative error due to finite intervals, and it is presented here.

INTRODUCTION

The BRDF of glossy samples has a very high and narrow peak around the specular direction; therefore, a very high angular resolution is required for its measurement, being this resolution determined by the measuring irradiation and collection solid angles. These solid angles are not infinitesimal because finite geometrical intervals cannot be avoided in the measuring systems. The conoscopic system to measure BRDF at the *Conservatoire National des Arts et Métiers*, CNAM [1, 2] allows small solid angles, and, in consequence, angular resolutions high enough for an adequate angular sampling of highly glossy surfaces, with a negligible impact of the finite intervals on the BRDF measurement. From these measures it is possible to estimate by numerical integration the impact of using larger finite intervals on a given sample. This method has been used in this work to propose recommendations on finite intervals (solid angles) to avoid systematic errors in BRDF measurements of samples of different gloss categories.

EXPERIMENTAL DATA

High-angular-resolution BRDF measurements of four samples belonging to four different gloss categories were carried out in CNAM. The name, the FWHM and the visual gloss of each sample are given in Table 1.

Table 1. Samples studied in this work.

Sample name	FWHM	Visual gloss
NCS4	7.91º	30
NCS5	3.70º	50
NCS6	2.59º	75
NCS7	0.84º	95

The measurements are represented in Figure 1. The angular resolution is 0.004º, except for NCS7, which is 0.015º.

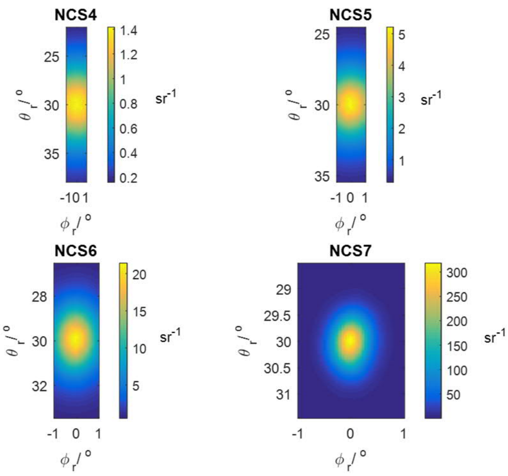

Figure 1. BRDF measurements of the four studied glossy samples around the specular direction. The false colour represents the value of the BRDF at each measurement geometry (see colour bar on the right side).

RESULTS AND DISCUSSION

The BRDF measurements were angularly integrated along a given interval to study the effect of reducing the angular resolution. This effect is equivalent to increase the illumination or collection solid angles widths. Solid angles with full-angle widths (κ) of 0.031º, 0.12º, 0.28º, 0.5º, 0.78º, 1.1º, 1.5º, 2º and 2.5º were selected.

The systematic error of the calculated BRDF by enlarging the solid angle width at the former values, are estimated by comparing them to those measured in the conoscopic system. The relevant angular variable to assess the variation of the BRDF of glossy samples is the aspecular angle (θ_{asp}). The lower it is, the most relevant is this variable, but its relevancy depends on the FWHM of the sample too. That is why, in a first approach to obtain a general equation for the systematic error, the BRDF was expressed as a function of a normalized angular variable, expressed as $\theta_N = \theta_{asp}$ / FWHM (Figure 2).

It is observed that the main BRDF change due to the specular peak is found between values of θ_N from 0 to 0.7 for all samples, unlike data in Figure 1, where the variation of BRDF occurs over a different interval of the angular variable for each type of sample.

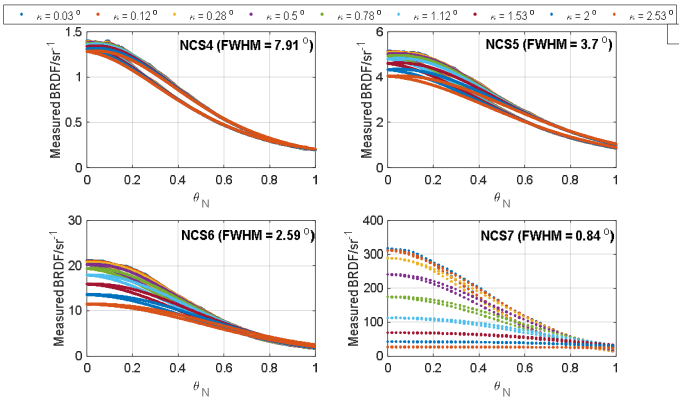

Figure 2. Calculated BRDF values for different solid angle widths, at ϕ_r = 0º, as a function of the proposed normalized angular variable $\theta_N = \theta_{asp}$ / FWHM. Each plot corresponds to a different sample.

The proposed normalized angular variable θ_N allows the relative angular distribution of relative errors to be normalized. However, the absolute values of these errors are still depending on κ and FWHM. A phenomenological equation can be fitted to estimate the systematic relative as a function of κ, FWHM and θ_N. The relative error positively depends on κ and negatively on FWHM. If this relative error is multiplied by $\kappa^{c2}/FWHM^{c1}$, with c1 = c2 = 1.3, the result of this factor is much more independent of κ and FWHM, as seen in Figure 3.

From this analysis was possible to obtain the following equation to estimate the systematic relative error due to finite intervals:

$$\varepsilon_r = \left(\frac{\kappa}{FWHM}\right)^{1.3} \times (0.34 - 0.37 \times \theta_N) \qquad (1)$$

This equation is only valid from θ_N = 0 to θ_N = 0.7.

CONCLUSIONS

High-angular-resolution BRDF measurements carried out at CNAM were assumed as true values to numerically evaluate the impact on the measurement in the case of using measuring systems with a lower angular resolution, limited by the illumination or collection solid angles. The analysis has allowed to obtain an equation that estimates the BRDF relative systematic error that would be made when measuring samples of a certain FWHM, with a given angular resolution, and at a specific aspecular angle. This should allow for recommendations to be given on solid angle widths for the measurement of the BRDF of glossy samples under different geometrical conditions.

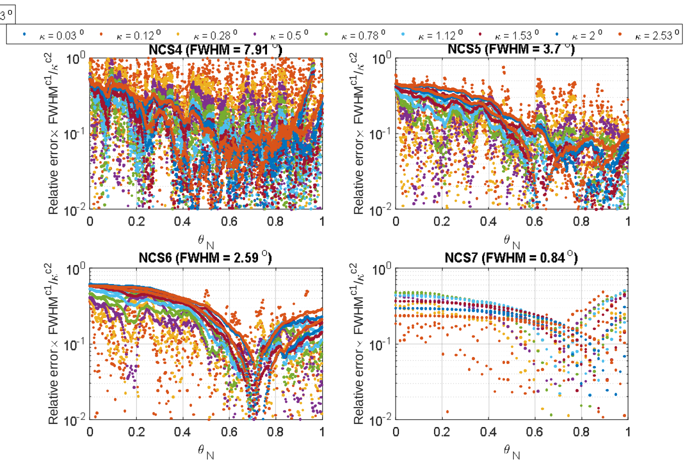

Figure 3. Relative error multiplied by $FWHM^{c1}/\kappa^{c2}$, with c1 =1.2 and c2 =1.425. The result of this factor is much more independent of κ and FWHM than the relative error.

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