A facility for measuring the BSSRDF

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This work presents a facility for measuring the Bidirectional Scattering-Surface Reflectance Distribution Function (BSSRDF), a function that describes the scattering in translucent materials. This facility targets an expanded uncertainty of 5 %. As a preliminary result, the half-angle of the collection solid angle was found to be the limiting uncertainty source.

INTRODUCTION

The reflectance of a translucent material cannot be explained only by the reflection at its surface but also by the scattering of the light inside its volume, which makes part of this light to emerge from other non-irradiated positions on the surface. To characterize the reflectance of translucent materials, a distribution function has been proposed that relates the incident radiant flux at a given point on the surface with the radiance at another point. This function, known as BSSRDF, is defined as[1]:

$$\mathrm{BSSRDF}(\mathbf{x}_\mathrm{i},\mathbf{r}_\mathrm{i};\mathbf{x}_\mathrm{r},\mathbf{r}_\mathrm{r}) = \frac{\mathrm{d}L_\mathrm{r}(\mathbf{x}_\mathrm{r};\mathbf{r}_\mathrm{r})}{\mathrm{d}\Phi_\mathrm{i}(\mathbf{x}_\mathrm{i};\mathbf{r}_\mathrm{i})} \qquad (1)$$

Fig. 1 shows a schematic representation of the geometrical variables involved in these measurements. The two cones represent incidence (subscript 'i') and collection ('r') solid angles, respectively.

The BSSRDF, although formally defined, has not been measured with metrological quality to date, and its definition as measurand must be established. As no primary equipment is available for measuring it, no reference exists for the measurement of subsurface scattering or translucency. This work aims to develop a facility for measuring the BSSRDF with expanded uncertainties under 5 %.

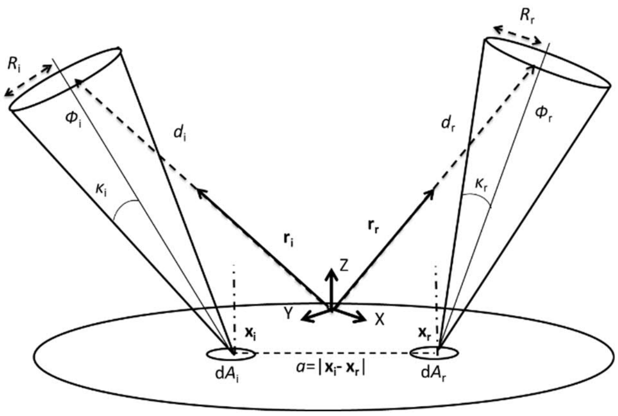

Figure 1. Definition of the geometrical variables involved in the measurement of the BSSRDF.

EXPERIMENTAL SETUP

A BSSRDF measuring system has been developed at CSIC, based on the Spanish gonio-spectrophotometer (GEFE)[2]. A photograph of the complete experimental device is shown in Fig. 2. The lighting system is located on the right side, which includes a Köhler system, allowing a uniform and directional irradiating spot on the sample, whose size can be modified by a diaphragm placed in front of the first Köhler's lens. A 1-mm diameter spot on the sample surface was selected for BSSRDF measurements. A 6-axis robotic arm (left) is used to position the sample at any orientation. Finally, the detector is located on a platform which can be moved around the sample on a circular ring. These degrees of freedom are enough to realize almost any incidence and collection bidirectional geometry. For providing spatial resolution, a CCD camera is used as detector, with an objective lens Navitar Zoom 7000 (18:180 mm). This detection system allows spatial resolution of 45 μm on the sample surface.

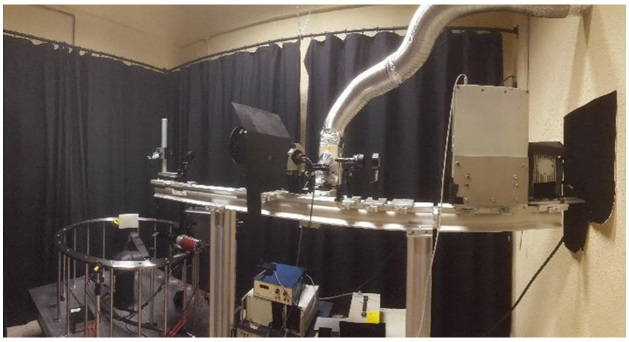

Figure 2. Gonio-spectrophotometer adapted for measuring the BSSRDF.

A measurement equation is derived from Eq. (1):

$$f_{\mathrm{ssr,k}} = \frac{1}{A_{\mathrm{fov}}\pi \sin^2 \kappa_{\mathrm{r}} \cos\theta_{\mathrm{r}}}\left(\frac{N_{\mathrm{k,r}}}{\sum N_{\mathrm{k,i}}}\right)\left(\frac{T_{\mathrm{i}}\eta_{\mathrm{e,i}}}{T_{\mathrm{r}}\eta_{\mathrm{e,r}}}\right)\left(\frac{t_{\mathrm{exp,i}}}{t_{\mathrm{exp,r}}}\right) \tag{2}$$

where:

$f_{\mathrm{ssr,k}}$: BSSRDF at the position of k$^{\mathrm{th}}$ pixel of the camera.
N_{k}: Response of the k$^{\mathrm{th}}$ pixel.
A_{fov}: Field of view area of one pixel.
T: Objective lens transmittance.
η_{e}: External quantum efficiency of the pixel.
t_{exp}: Exposure time.
θ_{r}: Angle of the collection direction respect to the normal of the sample.
κ_{r}: Half-angle of the collection solid angle (Fig. 1).

The ratio $T_{\mathrm{i}}\ \eta_{\mathrm{e,i}}$ / $T_{\mathrm{r}}\ \eta_{\mathrm{e,r}}$ represents the ratio of camera responsivities in two different conditions: directional illumination (without sample) and diffuse illumination (with sample out of specular conditions). An experimental procedure for measuring κ_{r} and the ratio $T_{\mathrm{i}}\ \eta_{\mathrm{e,i}}$ / $T_{\mathrm{r}}\ \eta_{\mathrm{e,r}}$ was developed. This procedure is based on locating a mirror on the sample position and moving it relatively to the camera objective at the measuring conditions, so that the relative responsivity of the camera is obtained for different incidence directions.

Also camera linearity and camera noise were assessed to estimate the BSSRDF uncertainty. The nonlinearity is important when incidence and collected radiant fluxes are evaluated with very different integration times. Specifically, the use of very low integration times should be avoided because smear is produced, the main cause of nonlinearity. So far, the uncertainty of κ_{r} is the limiting uncertainty source of the BSSRDF measurement, with an expanded uncertainty of about 5 %.

The detailed uncertainty budget and BSSRDF measurements of specially selected translucent samples will be shown during the conference. These measurements are obtained from images as those shown in Fig. 3, acquired with the presented facility.

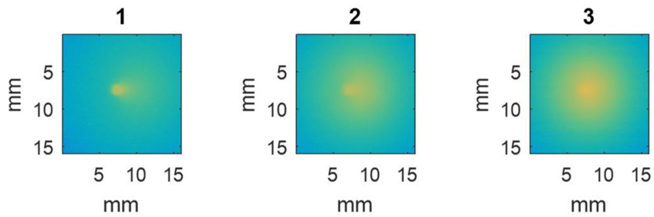

Figure 3. Images of three translucent surfaces irradiated by a 1-mm diameter spot centred on the image. The concentration of scattering particles increases from sample 1 to sample 3.

CONCLUSIONS

A gonio-spectrophotometer was adapted to build a primary facility for measuring the BSSRDF with a target expanded uncertainty of 5 %. Procedures are under development for measuring those variables required to obtain the BSSRDF. So far, the half-angle of the collection solid angle is the limiting uncertainty source.

ACKOWLEDGMENTS

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