Proceedings of NEWRAD 2014

Edited by

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Virtual experiment uncertainty analysis of robot-based gonioreflectometers

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The Physikalisch-Technische Bundesanstalt (PTB) is meanwhile operating two robot-based gonioreflectometer facilities for research and calibration purposes related to the Bidirectional Reflectance Distribution Function (BRDF). In the recent years new materials with new sophisticated reflection effects, like goniochromatism, sparkle and graininess, emerged into industrial application, requiring extended physical explanation using for instance the BRSSDF (Bidirectional Scattering Surface Reflectance Distribution Function), where also the position dependent reflection properties on a reflecting surface are taken into account. Due to the increase in complexity of the BRSSDF measurement, it is not feasible any more to apply the standard mathematical methods of the GUM (Guide to the Expression of Uncertainty in Measurement) which thus need to be extended by Monte Carlo Methods (MCM) and Virtual Experiments.

INTRODUCTION

The characterisation of diffuse reflecting surfaces in full 3D-space by means of the BRDF or even the BRSSDF (Fig. 1) is gaining more and more interest in industry, driven by increased requirements concerning the visual appearance of commercial products, [1, 2].

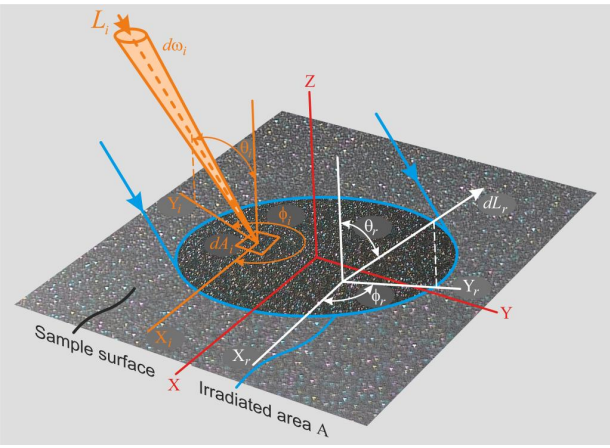

Figure 1. Geometry of incident and reflected beams according to a description of a surface via the BRSSDF.

The BRSSDF is given by a function S with a dependency upon the location of the point at which the incident flux strikes, upon the location of the point which the ray of radiance dL_r emerges and upon the directions involved, i.e.:

$$S = S(\theta_i, \phi_i, x_i, y_i; \theta_r, \phi_r, x_r, y_r) \quad (1)$$

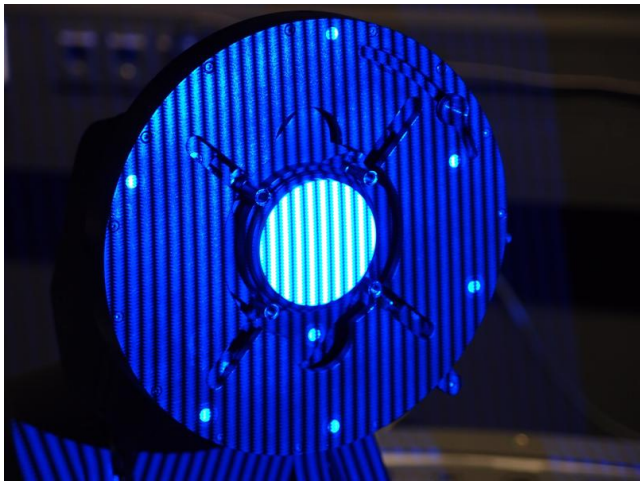

Figure 2. Alignment of a diffuse reflection standard attached to the robot-based gonioreflectometer with a 3D-scanner stripe-projection system.

Within the European Metrology Research Program (EMRP) of the European Commission a special project of coordinated R&D named "Multidimensional Reflectometry for Industry" was approved in the last year. The short name of the project is xD-Reflect, indicating the multi-dimensional aspects (x > 3) of modern reflectometry.

The project is divided into 5 scientific work packages entitled "Goniochromatism", "Gloss", "Fluorescence", "Modelling and Data Analysis" and "Visual Perception". PTB has the leadership of the "Goniochromatism" and "Modelling and Data Analysis" work packages. One important common task of the conjoint PTB-work within the 3-year work program of the project are computer-based virtual experiments in order to carry out sensitivity analysis by taking into account possible errors related to the geometric, spectrometric and optical setup of the real gonioreflectometers. Figure 2 shows part of the alignment

procedure of a diffuse reflection standard with a 3D-scanner stripe-projection system. These types of reflection standards are used for the transfer of the absolute diffuse reflection scale in directional geometries (spectral radiance factor) of PTB to customers in research and industry. Proper alignment of the sample orientation in relation to the incident and detection beam paths is essential in order to obtain small uncertainties.

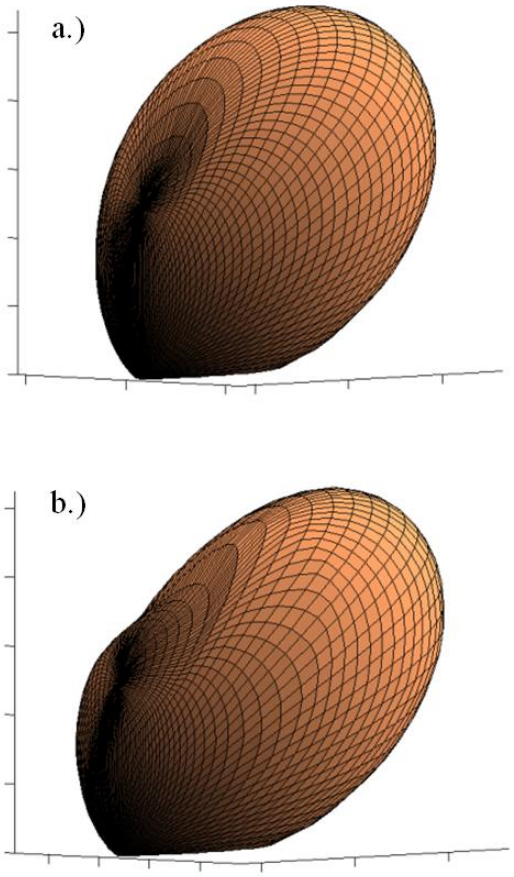

Figure 3. First simulated BRDF using a Phong-type BRDF-model for an incident angle of 45°, a.) perfect aligned gonioreflectometer, b.) gonioreflectometer with a misaligned detector.

SCIENTIFIC AND TECHNICAL OBJECTIVES

The evaluation of reliable uncertainties for complex measurements such as in robot-based gonio-reflectometry requires an appropriate mathematical modelling. On the basis of mathematical models also virtual computer experiments can be developed which can be employed to gain insight into the measurement system and to enable a characterisation of the whole measurement setup. Virtual computer experiments can especially be utilized to study the impact of certain misalignments within the measurement setup or to carry out sensitivity analyses in order to identify dominant uncertainty contributions.

For the robot-based gonioreflectometers of PTB [3, 4] the virtual computer experiment is designed by different interacting modules describing the light source, the goniometer setup with all the degrees of freedom for the movement, the surface under test and the detector. The surface under test is modelled by analytical BRDF functions and the simulation of the whole experiment is carried out via ray tracing techniques [5]. Figure 3 shows two simulated BRDF measurements for an angle of 45° of the incident beam obtained via virtual experiments. Figure 3b illustrates a first result of the impact of a misalignment in the detection beam path of the gonioreflectometer setup, inducing distortions in the resulting BRDF measurement.

ACKNOWLEDGMENTS

This work has been carried out within EMRP project IND52 "Multidimensional Reflectometry for Industry". The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

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