European Partnership on Metrology
Call 2023 –Fundamental Metrology, Industry, Normative and Research Potential

Selected Research Topic number: **SRT-i10**
Version: 1.0

Title: Multidimensional optical diffusion for the measurement of appearance

Abstract

Product appearance and visual branding are important drivers in consumer purchase because they underpin perceptions of 'quality' and 'desirability'. The control of appearance is thus essential for many industry sectors (e.g. automotive and cosmetics). Additionally, in industry sectors dealing with virtual objects (e.g. videogames, metaverse, virtual prototyping, digital twins) and 3D printing, the quality of the rendering and its realism are also essential. Therefore, it is crucial to improve the quality control and the virtual reproduction of the appearance of objects. Proposals addressing this SRT should i) improve the metrological characterisation of optical properties of complex surfaces, ii) simplify existing measurement concepts achieved at NMI level so these can be used in an industrial context, iii) setup quantifying tools for digital twins, reproduction and archiving of appearance, and iv) investigate metrological issues in bidirectional spectrophotometry to decrease the uncertainty on widely used quantities.

Keywords

Reflectance, Transmittance, Goniospectrophotometry, Appearance, Bidirectional Reflectance Distribution Function (BRDF), Bidirectional Transmittance Distribution Function (BTDF), Bidirectional Surface Scattering Reflectance Distribution Function (BSSRDF), Materials, Virtual reality

Background to the Metrological Challenges

The appearance of a product is well known to affect the end-user perception of its quality and therefore influence the purchase decision. As such, the control of appearance and its representation have a direct link to the success and competitiveness of industries. The global challenge of the measurement of the visual appearance has been highlighted by CIE [1] and EURAMET European Metrology Network (EMN) - Advanced Manufacturing.

In the last decade, Europe has proven to be in the forefront of the metrology of appearance. EMRP project IND52 xDReflect initiated a metrological force to develop measurement tools devoted to the metrology of appearance. Outputs of this project informed normative activity in EMPIR project 16NRM08 BiRD. After these, EMPIR project 18SIB03 BxDiff established new primary references at the national metrology institute (NMI) level for this field.

BRDF scales maintained by NMIs have been compared in IND52 xDReflect and 18SIB03 BxDiff, and new Calibration and Measurement Capabilities (CMCs) have been or are being claimed due to those efforts. However, the measurement of the BRDF at a few geometries is not enough to fully characterise the appearance of challenging surfaces and effects (e.g. brushed metals, functional surfaces, anisotropic samples and sparkle). For this, image-based goniospectrophotometers are required and have been developed at NMIs. However, they must be compared and tested in the measurement of difficult visual effects. Traceable BRDF measurements on non-flat surfaces have never been done even though the need has been expressed by industrials for more than a decade.

BTDF and BSSRDF primary scales have been established during 18SIB03 BxDiff at the NMI level. For both quantities, the uncertainties span between 1 % and 5 % depending on the sample. These developments have enabled work to start on the measurement of translucent materials, but further work is required for the integration of these quantities in industrial processes. Firstly, the uncertainty on BSSRDF measurement is still too high and must be reduced. Secondly, the equipment is too complex and measurements take too long; therefore a simplification is required. Thirdly, the measurement of the BSSRDF is still not sufficient to simulate the appearance of translucency in rendering models. Moving forward requires the measurement of effective

parameters such as scattering and absorption coefficients and the phase function of the material. These parameters, although essential for industry, are not measured currently.

Important work has been done in 18SIB03 BxDiff to develop standard artefacts for the traceability of BRDF, BTDF and BSSRDF. Samples exist, but further work is required to understand which and how many angular configurations are required to ensure a strong transfer of the scales to industry and to feed rendering models. Flat surface measurements and calibrations are made at the centimetre scale. However, industry needs measurements at the meter, millimetre and micrometre scale. A first attempt has been made during 18SIB03 BxDiff to extend the traceability of BRDF scale to micrometre. It reveals optical, instrumental and traceability issues that require additional work. Whereas the measurement of gloss has progressed significantly over the last decade, the measurement of mattness is inexistent, even though this visual effect is very much used in industry. Therefore, it is crucial for work on the optical and visual characterisation of mattness to start. With regards to translucency, several psychophysical studies have been published over the past 5 years but the link with BSSRDF and simplified quantities is still missing.

Characterisation of diffuse transmittance, total reflectance, transmittance haze and specular gloss are still performed using a relative methodology based on integrating spheres. Indirect measurements of these quantities using BRDF and BTDF measurements from goniospectrophotometers have been performed in 18SIB03 BxDiff and EMPIR project 20SCP01 SmartPhoRa. The results have shown that the scales obtained by both methods are not in the expected agreement, which requires further investigation.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the development of metrology capability in multidimensional optical diffusion for the measurement of appearance.

The specific objectives are

1. To develop and characterise image-based goniospectrophotometers, and use these to perform the traceable measurement of optical properties (e.g. BRDF, BTDF, BSSRDF) of manufactured surfaces e.g. anisotropic surfaces, non-flat surfaces, functional surfaces and translucent materials. The target measurement uncertainties are below 0.5 % for BRDF and BTDF, around 2 % for BSSRDF, depending on the wavelength.
2. To simplify the measurement conditions of complex scattering quantities (BRDF, BTDF, BSSRDF) realised at NMI level, so that these can be measured in industry set ups with target uncertainties below 2 % for BRDF and BTDF, around 4 % for BSSRDF, depending on the wavelength. To define quantifying tools for the digitalisation and reproduction of appearance of materials, including thresholding, sampling strategy and compression and interpolation models.
3. To develop measurement scales for translucency and mattness. This should include the definition of physical quantities (e.g. scattering and absorption coefficients, and phase function of the material) which correlate with the visual sensation and the proposal of protocols for their measurement with a target uncertainty of 5 %.
4. To tackle metrological issues in the field of bidirectional spectrophotometry that limit the knowledge and the uncertainties on spectrophotometric quantities, i.e., sphere-based quantities, transmittance of thick samples, multiscale traceability, effective refractive index, specular gloss index.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the EMN Advanced Manufacturing, measurement supply chain (NMIs, instrument manufacturers), standards developing organisations (ISO, CIE), and end users (e.g. automotive industry, video game developers, healthcare sector, visual arts sector, glass manufacturers).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMRP IND52 xDReflect, EMPIR 16NRM08 BiRD, 18SIB03 BxDiff and 20SCP01 SmartPhoRa projects and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.3 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 35 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the 'end user' community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the "end user" community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the automotive, healthcare and spectrophotometry sectors.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of the Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] 010_CIE Quantitative descriptions of appearance, https://metpart.eu/nrm-call-2023