# Publishable Summary for 16NRM08 BiRD

**Bidirectional Reflectance Definitions**

**Overview**

The commercial success of a product is often dependent on its aesthetic appearance. For this reason, different industrial sectors e.g. automotive coatings, cosmetics, printed materials, are continuously looking to develop new attractive visual effects. This project focuses on the pre-normative work required to clarify how measurements on standard materials and surfaces exhibiting goniochromatism, gloss and sparkle visual effects should be carried out. This will enable a reliable comparison of results provided by different measurement devices and better control of the visual effects of products.

**Need**

Objects are identified through their shape, size and “visual attributes” i.e. colour, gloss, translucency and texture. These attributes define the appearance of the objects. For industrial manufacturers, the appearance of a product is important at the quality control level (because the visual appearance informs the manufacturer on the constancy and reproducibility of its production) and at the commercial level (because the appearance of a product directly influences the customer and the purchase decision). Within the last 20 years, substantial effort has been undertaken by industrial manufacturers to create attractive and sophisticated visual effects. However, current standards on colour measurement (ISO 11664) and gloss measurement (ISO 2813) are not adapted anymore to the characterisation of sophisticated visual effects and no standard exists for Bidirectional Reflectance Distribution Function (BRDF) or sparkle. Following on from the need to characterise visual effects and the absence of standardisation and standard methods in this field, manufacturers of spectrophotometer systems and NMIs are developing their own instruments, using different optical parameters and methods of measurement. This leads to a lack of comparability in the BRDF, gloss and visual texture; three aspects which determine the appearance of a product. This situation gave in 2016 the impulse to CIE (Commission Internationale de l´Éclairage) to initiate work on BRDF through TC2-85.

**Objectives**

This project aims to clarify how BRDF measurements on both classical surfaces and surfaces exhibiting goniochromatism, gloss and/or sparkle visual effects, should be carried out.

The scientific and technical objectives of this project are to:

1. Propose standard parameters for the measurement of the BRDF of particular materials and optical surfaces in the visible range in order to improve the traceability to the SI between users and NMIs, and therefore to allow for better agreement between commercial goniospectrophotometers. The focus will be on i) settings of solid angles, ii) illuminated and measured areas, and iii) convergence of light beams. In addition, to provide guidance on how to sample the BRDF space efficiently and to propose a minimum number if measurement geometries according to the appearance properties of the specimen.
2. Propose arrangements for data handling and processing for BRDF measurements when a large amount of data is obtained.
3. Propose a new method for gloss measurement that correlates with visual perception. The contribution will be based on i) reflectance measurements, ii) visual evaluations and iii) definition of a standard gloss observer.
4. Propose a consensual definition of sparkle and graininess measurands and define procedures for their measurement in correlation with visual scales for sparkle and graininess.
5. Facilitate the uptake of the technology and guidance developed in the project by the measurement supply chain, e.g. instrument manufacturers and end-users, e.g. automotive, cosmetics, pigments, packaging and 3D printing industries. In addition, to contribute to the standards development work of international standardisation bodies, e.g. CIE. Dissemination of project results will take place as early as possible to establish a standardised approach.

**Progress beyond the state of the art**

According to the type of sample (glossy, goniochromatic, diffuse, etc.), BRDF measurement results can greatly depend on the measurement settings. This project has categorised visual effects in different categories (Quasi Lambertian, neutral, isotropic chromatic, glossy and goniochromatic). For each category, the influence of the solid angles used, spectral bandwidth, polarisation, shape and size of the illuminated area have been tested with error below 5 %. Novel knowledge on BRDF is being created and disseminated to CIE TC2-85 as a necessary step to standardise BRDF measurements.

As a result of the measurements performed in this project, the consortium is now able to recommend sampling strategies of the BRDF space for each category of samples with an estimate of the error made in the reconstruction of the full BRDF. For goniochromatic samples, 10 geometries are enough if the user accepts an average error of ∆E = 5. Around 70 geometries are necessary to drop at ∆E = 3. For gloss samples, the sampling strategy is expressed as an angular step requested to measure the specular peak. This step can vary from 1.5° to 0.03° according to the level of gloss.

A convenient method has been proposed to arrange BRDF data to facilitate communication between NMIs, instrument manufacturers and industry using BRDF data. The file structure is based on JSON to keep the readability of the file and allow the possibility of returning metadata without the need of additional parsing. A visualisation software is also under development to provide open access visualisation of the variation of the BRDF with the direction of observation, for i) one specific direction of illumination, ii) one wavelength and iii) one polarization. In the case of goniochromatic samples, colour differences and tolerances for 2D and 3D objects will be implemented in this applet.

A new CIE Technical Committee, JTC17, has been set up with the objective to propose standardised assessment methods and improved optical evaluation methods for the quantification of gloss. The consortium will bring to this technical committee expertise in BRDF measurement of the specular peak, psychophysical scales and a new type of BRDF measurement coming from a new setup developed in the project. All this material will support the objective of this technical committee to define a “standard” observer, which is based on the average result from a number of observers, taking into account one or more predefined sets of assessment conditions.

As a result of a proposal formulated by the project partners, a new CIE Technical Committee, JTC12, has been established to work on the standardisation of sparkle and graininess of coatings. A measurement protocol to quantify the sparkle effect is in progress to provide high inter laboratory compatibility. A measurement protocol has been also set up to quantify graininess. A comparison is being done at the moment to test the quality of this protocol between NMIs. All these results will be provided to JTC12 in order to support its work on a future normalisation of the measurement of sparkle and graininess.

**Results**

*Standard parameters for measuring BRDF*

A categorization of samples and a definition of angles of illumination and detection has been submitted to CIE TC2-85 and accepted at their annual meeting in October 2017. It has been agreed that:

* all angles must be defined according to the normal of the sample;
* the recommendation for BRDF measurements will concern quasi-lambertian, neutral (achromatic), non-neutral (chromatic), gloss and goniochromatic (including “interference pigments” and “diffractive pigments”) samples;
* sparkle, graininess, spatially non-isotropy, brushed metals fabrics and textile will not be covered by the recommendation.

The measurement of the effect of solid angles and convergence of light beams on BRDF for glossy sample has been carried out at CNAM. The recommendation is to use angular resolutions varying from 1.5° for matt samples to 0.03° for high gloss samples (see [here](http://files.cie.co.at/x046_2019/x046-OP88.pdf)). The evaluation of the effect of solid angle and spectral bandwidth on goniochromatism samples based on diffractive pigments has been discussed during the last TC2-85 but no consensus has been reached. Further measurements are still ongoing to support this TC’s decision.

The sampling angular strategy to be adopted for the characterisation of goniochromatic effects, coming from interference ([here](https://www.osapublishing.org/josaa/abstract.cfm?uri=josaa-33-1-1)) and diffractive pigments ([here](https://pdfs.semanticscholar.org/6e5a/466fb202cd00e81379433be642569e9f3a3a.pdf)) has been elaborated by PTB and CSIC, and has been adopted by TC2-85 in June 2019.

The study on the effect of the shape of the illuminated area has shown that this effect can be neglected on diffuse and glossy samples. The effect of the spatial homogeneity of the illuminated area, at the opposite, seems to have an effect on the BRDF measurements and further investigation on this topic is still in progress at CNAM and PTB.

*BRDF data handling and processing*

Aalto and UA completed the review on existing commercial colour management software for colour quality control of surface appearance. A set of BRDF file formats used in commercial devices (multi-angle spectrophotometers, gonio-spectrophotometers, etc.) and theoretical models has been collected by the project partners from industrial stakeholders, rendering software designers, and international standards (ASTM, CIE, etc.). From this survey, and after discussion in progress meetings, a datafile format was agreed by the consortium and stakeholders in May 2019. The *JSON* format was selected because it is more readable than *xml* format and allows simply return field "metadata" from file without the need of additional parsing. The decision was reported to CIE TC2-85 and CIE TC4-50 during the CIE meetings in June 2019. The consortium is testing it and will propose amelioration over the period November 2018 to November 2019. The final version is expected to be adopted in November 2019.

Aalto, CSIC and UA proposed appearance descriptors (polar mode, colour travel, digital RGB visualisation, etc.). All these elements have been presented and discussed with the project’s stakeholders at a progress meeting (April 2018). An open source code named [BiRDview](https://birdview-app.herokuapp.com/) has been designed by using Python whose main function is to show BRDF measurements from different equipment. In addition, different appearance descriptors as colour travel or digital RGB visualization have been considered to obtain a complete material characterisation. The applet can be tested by any stakeholder or general public. It takes as input file measurement data formatted in JSON. Feedback is welcome on BiRD’s website [here](https://www.birdproject.eu/contact/).

*Gloss measurement and visual perception*

KU Leuven, CNAM and Innventia summarised the state-of-the-art of gloss measurement and gloss perception in a Technical Report that was sent to CIE Division 1 in January 2018. Together with the report, a database of key research related to the subject was developed and made accessible on the project website ([here](https://www.birdproject.eu/references/)). Specific terminology related to gloss, encountered in ISO standards, was summarised in a glossary of terms, together with their definition and reference to the defining standard(s). KU Leuven submitted to CIE Division 1 the creation of a Technical Committee on gloss in July 2018. The Board of administration of CIE proposed to make it a joint TC, including CIE divisions 1 (vision and colour), 2 (Measurement of light) and 8 (Image technology). The proposal was accepted and “[JTC 17 (D1/D2/D8)](http://www.cie.co.at/technicalcommittees/gloss-measurement-and-gloss-perception-framework-definition-and-standardization): Gloss measurement and gloss perception: A framework for the definition and standardization of visual cues to gloss“ is now active. Experts are welcome.

A new measuring equipment devoted to the measurement of gloss has been developed at KU Leuven. This device, with an optical design based on ISO 2813 recommendation, proposes advanced features that allow accessing the shape of the specular peak and materials visual properties like “orange peel” or “contrast gloss”. Measurement data provided by this new measurement approach will be of great support for JTC 17 works (More details are [here](https://rdcu.be/buz84)).

*Sparkle measurement and visual perception*

A proposal for the creation of a CIE TC was prepared by CSIC, UA, CMI, PTB, CNAM and METAS and presented at the CIE mid-term meeting. The proposal has been accepted and established as a Joint Technical Committee (JTC 12), involving again CIE divisions 1, 2 and 8. The seventh version of the report, written by CSIC, PTB, CMI, UA and METAS is under discussion by the 21 members of the JTC (July 2019). It includes methodology for the spectrophotometric measurements related with sparkle and graininess, some definitions and concepts regarding contrast threshold, and a physical model which can describe both sparkle and graininess.

In parallel, a set of nine samples representating the full range of sparkle & graininess were selected and have been circulated among CSIC, PTB, METAS and CMI. The samples have been measured according to the methodologies proposed in the JTC 12 draft report named “Methodology for the acquisition of sparkle images” and “Methodology for the acquisition of graininess images”. Some issues regarding the methodology were observed, and a second measurement campaign is in process among CSIC, PTB, METAS and CMI with an improved method.

To complete these metrological measurements, psychophysical experiments have been developed by UA to progress in the identification of visual properties and principal components of sparkle and graininess. The resulting definition of the measurand for graininess were published in a paper titled "Definition of a measurement scale of graininess from reflectance and visual measurements" (see [here](https://www.osapublishing.org/oe/abstract.cfm?uri=oe-26-23-30116)). Visual scales for graininess were established and have been published (see [here](https://www.tandfonline.com/doi/full/10.1080/09500340.2019.1589006)). Visual scales for sparkle are under work and should be ready by the end of 2019.

**Impact**

A project website has been created ([www.birdproject.eu](http://www.birdproject.eu)) with a restricted area for the 35 registered stakeholders. The website has already had more than 27,000 visits. The project is in close contact with its stakeholders, who regularly attend the project meetings. Newsletters have been sent to stakeholders every six months, and most recently every two months to update on new results. A stakeholder committee with 36 members representing industrial sectors such as instrumentation, pigments and coatings, automotive, and pulp and papers (from 12 countries) has been created. Since the launch of the project, 7 new stakeholders, mainly spectrophotometers manufacturers have joined the group.

At the project meeting organised in April 2018, the consortium shared its results and discussed with manufacturers of spectrophotometers the main requirements of the universal BRDF data file. A 90 min breakout session offered the opportunity to obtain feedback and discuss needs, issues and collaborations. This meeting had 48 attendees, from which 30 were stakeholders representing 21 different companies. In October 2018, the consortium organised a one day workshop entitled “Open questions on gloss measurement”, which was disseminated on different networks and covered all aspects of gloss, from cognitive science to virtual rendering. The CIE JTC on gloss has been introduced to the 22 stakeholders who attended the workshop. In May 2019, a 3rd progress meeting was held. Progress of the project have been presented and discussed with stakeholders. A total of 39 persons attended including representatives of 18 industrial organisations. Two weeks later, the consortium organized a workshop entitled “Open questions on visual appearance”, which was attended by 32 persons Master and PhD students, industrials and academics.

To promote the uptake of the outputs of this project by the wider stakeholder community, the partners have given 25 oral presentations at international conferences over the last 27 months of the project, including three invited talks. Five peer reviewed papers have already been published.

*Impact on industrial and other user communities*

The recommendations on BRDF, sampling strategy, sparkle, gloss and file format will be made available to stakeholders and end-users from different industrial sectors e.g. instrument manufacturers, automotive, cosmetics, pulp and paper and printing industries. To ensure the relevance of the outputs to the industrial community, this project has established a stakeholder committee (SC) with members from these different industrial sectors and is seeking feedback on the work being carried out. Consultation of the SC happens during progress meetings.

The uptake of the outputs of this project by the industrial community will enable the development of novel instruments which will increase the competitiveness of European industries. The recommendations on the optical parameters for the measurement of BRDF will be crucial for instrument manufacturers to produce a new generation of spectrophotometers and to enable industrials to move from visual evaluation to objective BRDF measurement, leading to better control of the appearance of their products and less rejection by the customer. The uptake of adequate and trusted definitions of measurands and measurement procedures for sparkle and graininess that will be proposed in this project will enable the design and development of dedicated instruments, which will benefit in particular the automotive industry, where more than 90 % of car paint show a sparkle effect and where the need of a reliable and traceable measurement is urgent. The uptake of the recommendations for the characterisation of the full BRDF of goniochromatic visual effect pigments will support the production of multi-angle spectrophotometers and promote the confidence of end-users that the best geometries can be used to characterise the product.

*Impact on the metrology and scientific communities*

In the absence of standardisation, the primary facilities developed for measuring BRDF are made to be very versatile in order to satisfy particular customer requirements. In some cases, this increases the measurement time and the measurement uncertainty. The take up of the technical recommendation on BRDF will enable NMIs to develop transfer reference facilities based on commercial instruments developed by stakeholders of the project. Existing calibration services can be automated at the NMI and calibration laboratory level, resulting in a reduction of calibration costs and time, and improvement of the traceability.

The normative work carried on in this project supports the development of a new generation of spectrophotometers that will increase the need of calibration and traceability. As a result, the metrological community will have to and be able to develop new calibration services.

Sparkling is a challenging effect that presents a huge radiance dynamic in a very narrow angular angle. For the measurement of sparkle and graininess~~,~~ NMIs have integrated Imaging Radiance Measuring Devices (IRMD) in their goniospectrophotometers. Works carried on sparkle improve the metrology for the characterisation of IRMDs. This creates impact in near-field radiometry and hyperspectral techniques, and triggers the development of NMI capabilities in this field.

*Impact on relevant standards*

This project has a direct impact on different standardisation bodies working on new or improved standards, in particular:

* [CIE TC 2-85](http://www.cie.co.at/technicalcommittees/recommendation-geometrical-parameters-measurement-bidirectional-reflectance), whose aim is to provide geometrical recommendations for the BRDF measurement according to the type of sample under investigation.
* [CIE JTC 12](http://www.cie.co.at/technicalcommittees/measurement-sparkle-and-graininess), whose aim is to provide a methodology to measure sparkle and graininess, and to develop a measurement scale.
* [CIE JTC 17](http://www.cie.co.at/technicalcommittees/gloss-measurement-and-gloss-perception-framework-definition-and-standardization), whose aim is to provide recommendations for standardised visual assessment conditions of gloss and to make recommendations for the definition of a standard gloss observer.

The outputs of this project are being disseminated to these committees through technical reports and oral presentations at each JTC and TC meeting. BRDF datafile format has been introduced to users of CIE [TC4-50](http://www.cie.co.at/technicalcommittees/road-surface-characterization-lighting-applications), *Road Surface Characterization for Lighting Applications*. National e.g. DIN NA 002-00-07 AA, SIS/TK 157, and international e.g. ISO/TC6, ISO/TC174/WG03 standardisation bodies are also briefed on the project’s results at committee meetings. Members of the CIE TC2-85, DIN- FNF/FNL, “Farbmetrik“ and of DfwG WG “Multigeometrie”, were updated about the progress of this project by oral presentations given during their annual meeting.

*Longer-term economic, social and environmental impacts*

So far, no standard observer exists for gloss. After 20 years of active research it is now possible to define a CIE gloss standard observer. This will enable the development of new gloss measurement devices and management of gloss, based on measurements and not on visual assessment. Gloss measurement can then be integrated into CIE colour appearance models to help manufacturers predict or control the appearance of their product. In the long term, this is expected to have an economic impact for industries where the control of gloss is crucial, i.e cosmetics, 3D printing, textile, pulp & paper.

Following on from the pre-normative work undertaken by this project on BRDF, it will be possible for CIE, in the future, to adopt a standard observer based on the full BRDF measurement, potentially facilitating the management of the appearance as a whole.

**List of publications**

G. Ged, « Métrologie du brillant, développement et caractérisation psychophysique d'échelles de brillants », PhD Thesis, September 2017, <https://tel.archives-ouvertes.fr/tel-01683126>

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T. Quast, A. Schirmacher, K.-O. Hauer, A. Koo, “Polarization properties and microfacet-based modelling of white, grey and coloured matte diffuse reflection standards”, Journal of Physics, vol **972** (2018), <https://iopscience.iop.org/article/10.1088/1742-6596/972/1/012024>

E. Perales, F.J. Burgos, M. Vilaseca, V. Viqueira, F.M. Martínez-Verdú, J. Pujol, “Graininess characterization by multidimensional scaling”, Journal of modern optics, **66**(9), pp 929-938, (2019), <https://doi.org/10.1080/09500340.2019.1589006>

F. B. Leloup, J. Audenaert, P. Hanselaer, “Development of an image-based gloss measurement instrument”, J. Coat. Technol. Res, **16**(4), pp 913-921, (2019), <https://rdcu.be/buz84>

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| Project start date and duration: | | | 1 May 2017, 36 months | |
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| Chief Stakeholder Organisation: n/a | | Chief Stakeholder Contact: n/a | | |
| Internal Funded Partners:  1 CNAM, Paris  2 Aalto, Finland  3 CMI, Czech Republic  4 CSIC, Spain  5 PTB, Germany  6 RISE, Sweden | External Funded Partners:  7 Innventia, Sweden  8 KU Leuven, Belgium  9 UA, Spain | | | Unfunded Partners:  10 CI, New Zealand  11 METAS, Switzerland |
| RMG: - | | | | |