Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

WP4: Modelling and data analysis

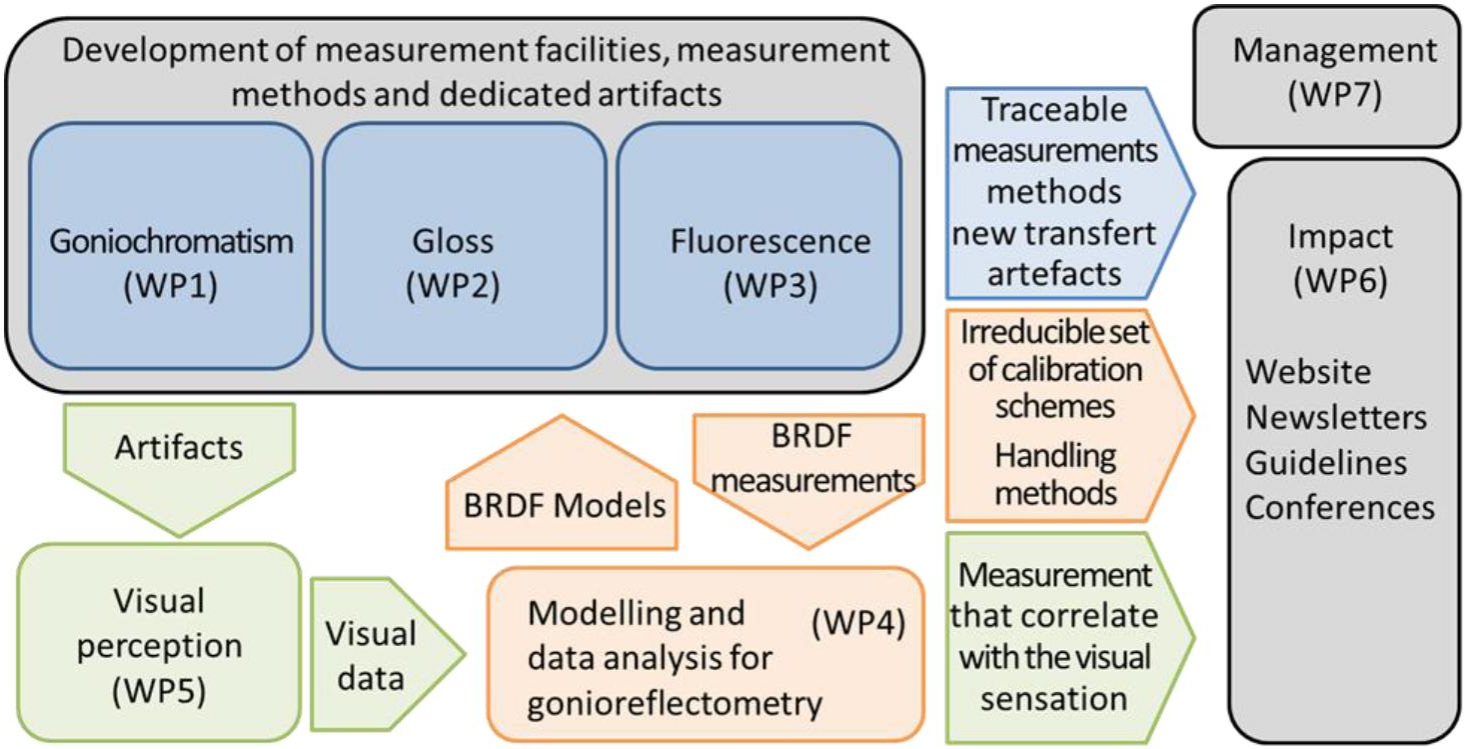
6th Progress meeting for JRP xDReflect :

Multidimensional Reflectometry for industry

21th – 23th June 2016, INRIM, Torino, IT

Agenda

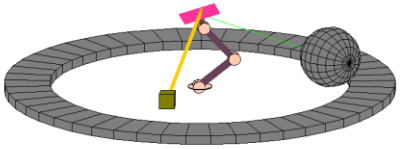
- **WP4 Objectives** (*G. Wübbeler*)
- **Machine learning and statistical analysis for visual appearance data** (*M. Langovoy*)
- **Data analysis of spectral BRDF of coatings with diffraction pigments** (*A. Ferrero*)



WP4: Modelling and data analysis

WP4 Tasks

- **Modelling BRDF measurements**



- **Efficient geometrical sampling strategies**

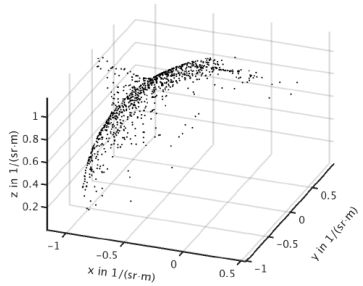


Fig 7: Gaussian sampling concentrated at the peak

- **Uncertainty evaluation for CIELAB colour coordinates**

- **Modelling visual perception based on reflectometry measurements**

Uncertainty evaluation for CIELAB colour coordinates

D 4.4.1
Linearised uncertainty propagation scheme for CIELAB colour coordinate

3 Estimates and uncertainty propagation

Given the estimates $\widehat{X}$, $\widehat{Y}$ and $\widehat{Z}$ along with the 3×3 covariance matrix $V_{(X,Y,Z)}$ for the tristimulus values X, Y and Z, application of GUM-S2 [2] then yields the following expressions for the resulting estimates $\widehat{L}$, $\widehat{a}$, $\widehat{b}$ and their associated covariance matrix $V_{(L,a,b)}$

$$\widehat{L} = 116 f(\widehat{Y}/100) - 16 \quad (7)$$

$$\widehat{a} = 500 \left(f(\widehat{X}/95.047) - f(\widehat{Y}/100) \right) \quad (8)$$

$$\widehat{b} = 200 \left(f(\widehat{Y}/100) - f(\widehat{Z}/108.883) \right) , \quad (9)$$

together with their associated covariance matrix $V_{(L,a,b)}$

$$V_{(L,a,b)} = C V_{(X,Y,Z)} C^T , \quad (10)$$

with inputs from CSIC and MSL

Uncertainty evaluation for CIELAB colour coordinates

D 4.4.2

Specification of the applicability range of the uncertainty evaluation schemes and report of the comparison of the linearised and Monte Carlo methods for evaluating uncertainty

1. Define the number M of Monte Carlo samples to be drawn. M should be large enough so that the results have sufficiently stabilized. We recommend to use $M = 10^6$, and to repeat the whole process several times to ensure that the results have stabilized. We refer to [2] for more advanced, sequential schemes to determine the number of Monte Carlo samples.
2. For $k = 1, 2, \ldots, M$ repeat
   (a) Draw a random sample X_k, Y_k, Z_k from the distribution $N\left(\hat{X}, \hat{Y}, \hat{Z})^T, V_{(X,Y,Z)}\right)$ for the tristimulus values. We note that software for drawing random numbers from a multivariate normal distribution is readily available.
   (b) Apply the transformation (1)-(3) to obtain the sample $(L_k, a_k, b_k)^T$ from the sought distribution for the CIELAB color coordinates.
3. Calculate an estimate for the CIELAB color coordinates according to

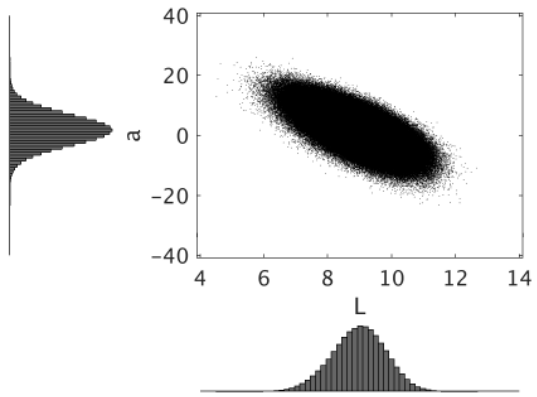
$$(\hat{L}, \hat{a}, \hat{b})^T = \frac{1}{M}\sum_{k=1}^{M}(L_k, a_k, b_k)^T, \tag{5}$$

along with its associated covariance matrix

$$V_{(L,a,b)} = \frac{1}{M-1}\sum_{k=1}^{M}\left((\hat{L}, \hat{a}, \hat{b}) - (L_k, a_k, b_k)\right)^T\left((\hat{L}, \hat{a}, \hat{b}) - (L_k, a_k, b_k)\right). \tag{6}$$

4. Calculate a 95 % coverage interval

$$I_L = [L_{(\alpha M)}, L_{((\alpha+0.95)M)}] \tag{7}$$



(a) Joint distribution of (L, a)

with inputs from CSIC and MSL

WP4 Deliverables

4.1.1	Empirical BRDF model for standard reference materials
4.1.2	Parameter estimates determined from BRDF measurements on standard reference materials
4.1.3	Results and Report of the sensitivity analysis for BRDF measurements on standard reference materials
4.1.4	Publication about the virtual computer experiment and the sensitivity analysis on standard reference materials
4.2.1	Empirical BRDF model for goniochromatism and empirical BRDF model for gloss
4.2.2	Parameter estimates determined from BRDF measurements on goniochromatism and gloss
4.2.3	Result of sensitivity analysis for BRDF measurements on goniochromatism and gloss
4.2.4	Publication about the virtual computer experiment and the sensitivity analyses on goniochromatism and gloss
4.3.1	Assessment of different sets of geometries for BRDF measurements
4.3.2	Determination of efficient sampling strategies via experimental design
4.3.3	Results by PCA approach
4.3.4 (REG(UA) D3.1)	Extension of PCA analysis for colour tolerances and formulation for gonio-apparent colours
4.3.5 (REG(UA) D3.2)	Extension of a commercial xDNA algorithm for colour tolerances and formulation of gonio-apparent colours

	4.3.6 (REG(UA) D3.3)	Extension of PCA analysis for colour tolerances and formulation for gonio-apparent colours
	4.3.7	Documentation of the development and assessment of efficient sampling strategies
PTB	4.4.1	Linearised uncertainty propagation scheme for CIELAB colour coordinates
PTB	4.4.2	Specification of the applicability range of the uncertainty evaluation schemes and report of the comparison of the linearised and Monte Carlo methods for evaluating uncertainty
CNAM	4.5.1 (REG(KU Leuven) D6.1)	Computation of model parameters for separate perception functions for gloss, fluorescence and goniochromatic appearance
CNAM	4.5.2 (REG(KU Leuven) D6.2)	Peer reviewed paper on the computation of model parameters for the separate perception functions for gloss, fluorescence and goniochromatic appearance
REG(UA)	4.5.3 (REG(UA) D3.4)	Report on the correlation of principal components of the visual measurements
PTB	4.5.4 (REG(KU Leuven) D6.3) (REG(UA) D3.5)	Development of a total appearance model and uncertainty evaluation of the predictions
INRIM	4.5.5	Analysis of panellist descriptors about colour perception under different environmental conditions documented in a peer reviewed journal paper and submitted for publication

WP4 Deliverables

4.1.1	Empirical BRDF model for standard reference materials
4.1.2	Parameter estimates determined from BRDF measurements on standard reference materials
4.1.3	Results and Report of the sensitivity analysis for BRDF measurements on standard reference materials
4.1.4	Publication about the virtual computer experiment and the sensitivity analysis on standard reference materials
4.2.1	Empirical BRDF model for goniochromatism and empirical BRDF model for gloss
4.2.2	Parameter estimates determined from BRDF measurements on goniochromatism and gloss
4.2.3	Result of sensitivity analysis for BRDF measurements on goniochromatism and gloss
4.2.4	Publication about the virtual computer experiment and the sensitivity analyses on goniochromatism and gloss
4.3.1	Assessment of different sets of geometries for BRDF measurements
4.3.2	Determination of efficient sampling strategies via experimental design
4.3.3	Results by PCA approach
4.3.4 (REG(UA) D3.1)	Extension of PCA analysis for colour tolerances and formulation for gonio-apparent colours
4.3.5 (REG(UA) D3.2)	Extension of a commercial xDNA algorithm for colour tolerances and formulation of gonio-apparent colours

	4.3.6 (REG(UA) D3.3)	Extension of PCA analysis for colour tolerances and formulation for gonio-apparent colours
	4.3.7	Documentation of the development and assessment of efficient sampling strategies
PTB	4.4.1	Linearised uncertainty propagation scheme for CIELAB colour coordinates
PTB	4.4.2	Specification of the applicability range of the uncertainty evaluation schemes and report of the comparison of the linearised and Monte Carlo methods for evaluating uncertainty
CNAM	4.5.1 (REG(KU Leuven) D6.1)	Computation of model parameters for separate perception functions for gloss, fluorescence and goniochromatic appearance
CNAM	4.5.2 (REG(KU Leuven) D6.2)	Peer reviewed paper on the computation of model parameters for the separate perception functions for gloss, fluorescence and goniochromatic appearance
REG(UA)	4.5.3 (REG(UA) D3.4)	Report on the correlation of principal components of the visual measurements
PTB	4.5.4 (REG(KU Leuven) D6.3) (REG(UA) D3.5)	Development of a total appearance model and uncertainty evaluation of the predictions
INRIM	4.5.5	Analysis of panellist descriptors about colour perception under different environmental conditions documented in a peer reviewed journal paper and submitted for publication

?

WP4 Deliverables

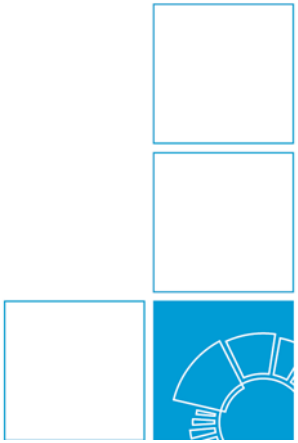
4.1.1	Empirical BRDF model for standard reference materials
4.1.2	Parameter estimates determined from BRDF measurements on standard reference materials
4.1.3	Results and Report of the sensitivity analysis for BRDF measurements on standard reference materials
4.1.4	Publication about the virtual computer experiment and the sensitivity analysis on standard reference materials
4.2.1	Empirical BRDF model for goniochromatism and empirical BRDF model for gloss
4.2.2	Parameter estimates determined from BRDF measurements on goniochromatism and gloss
4.2.3	Result of sensitivity analysis for BRDF measurements on goniochromatism and gloss
4.2.4	Publication about the virtual computer experiment and the sensitivity analyses on goniochromatism and gloss
4.3.1	Assessment of different sets of geometries for BRDF measurements
4.3.2	Determination of efficient sampling strategies via experimental design
4.3.3	Results by PCA approach
4.3.4 (REG(UA) D3.1)	Extension of PCA analysis for colour tolerances and formulation for gonio-apparent colours
4.3.5 (REG(UA) D3.2)	Extension of a commercial xDNA algorithm for colour tolerances and formulation of gonio-apparent colours

	4.3.6 (REG(UA) D3.3)	Extension of PCA analysis for colour tolerances and formulation for gonio-apparent colours
	4.3.7	Documentation of the development and assessment of efficient sampling strategies
PTB	4.4.1	Linearised uncertainty propagation scheme for CIELAB colour coordinates
PTB	4.4.2	Specification of the applicability range of the uncertainty evaluation schemes and report of the comparison of the linearised and Monte Carlo methods for evaluating uncertainty
CNAM	4.5.1 (REG(KU Leuven) D6.1)	Computation of model parameters for separate perception functions for gloss, fluorescence and goniochromatic appearance
CNAM	4.5.2 (REG(KU Leuven) D6.2)	Peer reviewed paper on the computation of model parameters for the separate perception functions for gloss, fluorescence and goniochromatic appearance
REG(UA)	4.5.3 (REG(UA) D3.4)	Report on the correlation of principal components of the visual measurements
PTB	4.5.4 (REG(KU Leuven) D6.3) (REG(UA) D3.5)	Development of a total appearance model and uncertainty evaluation of the predictions
INRIM	4.5.5	Analysis of panellist descriptors about colour perception under different environmental conditions documented in a peer reviewed journal paper and submitted for publication

Publication on CIELAB uncertainties ?

Agenda

- **WP4 Objectives** (*G. Wübbeler*)
- **Machine learning and statistical analysis for visual appearance data** (*M. Langovoy*)
- **Data analysis of spectral BRDF of coatings with diffraction pigments** (*A. Ferrero*)



Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Abbestr. 2-12
D-10587 Berlin

Dr. Gerd Wübbeler
8.42, Data Analysis and Measurement Uncertainty

Telefon: +49 30 3481 7242
E-Mail: gerd.wuebbeler@ptb.de
www.ptb.de