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Webinar –Uncertainty calculation of luminance coefficient

[measured with reflecto-goniometers and related to geometrical characteristics]

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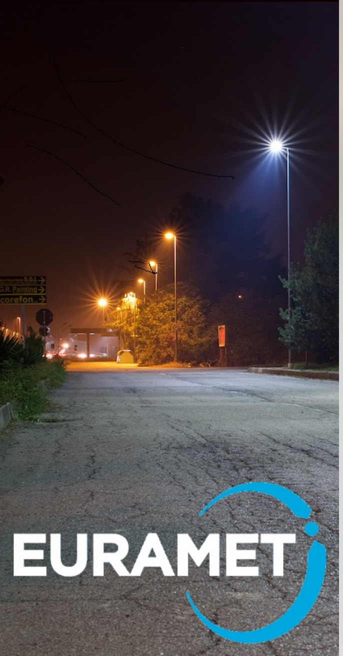
25th February 2021



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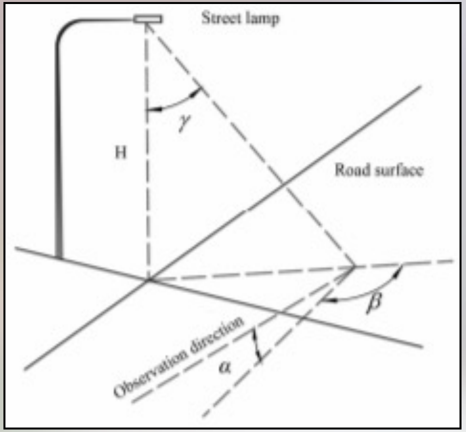
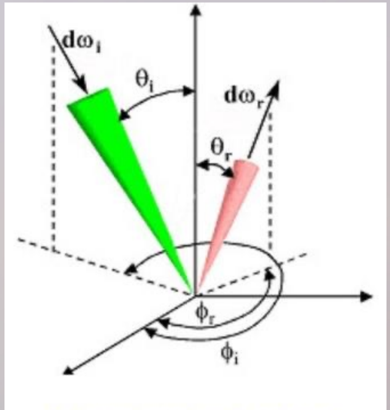
Measured quantity : luminance coefficient q – definitions



Luminance coefficient:

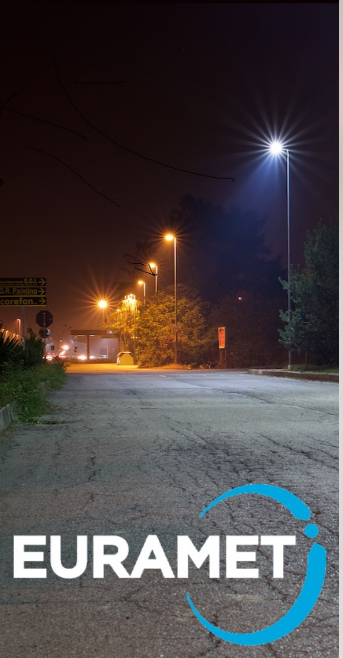
$$q(\alpha,\beta,\gamma)=\frac{L(\alpha,\beta,\gamma)}{E(\beta,\gamma)},$$



Bidirectional reflectance distribution function (BRDF)

$$f(\theta_i,\phi_i,\theta_r,\phi_r)=\frac{dL_r(\theta_r,\phi_r)}{dE_i(\theta_i,\phi_i)}$$

- α: viewing angle
- β: angle between the lighting plane and the viewing plane
- ϒ: lighting angle
- δ, angle between the viewing plane and the road axis at the considered viewing point -> **neglected because of isotropy of pavement reflectance**



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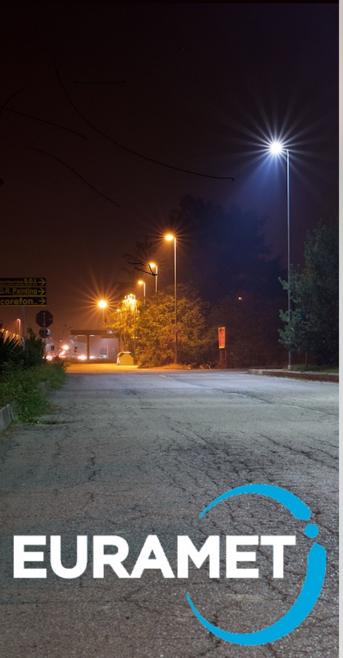
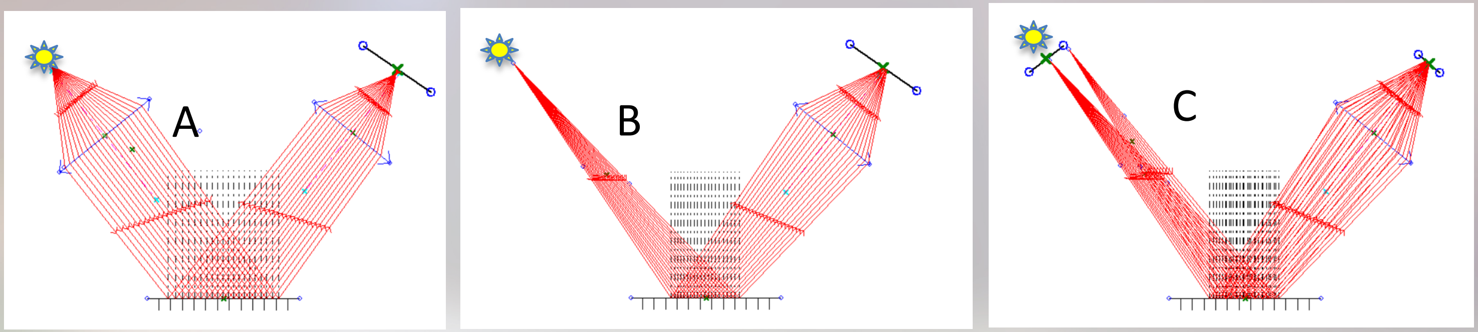


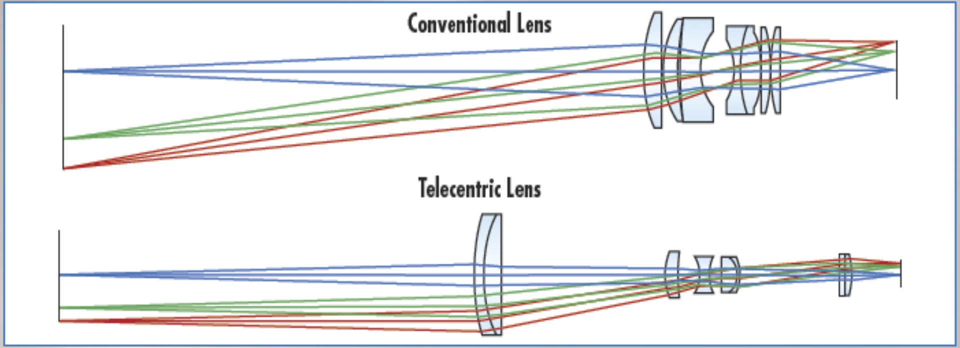
Impact of optical systems characteristics for illumination and detection : simple cases

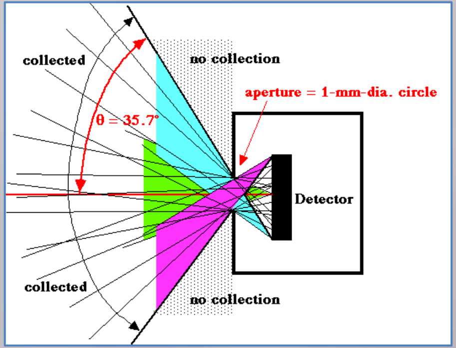


A : Almost perfect collimated systems , **B** : no optics direct lighting from a point source – FOV effect – **C** : no optics - FOV effect and aperture effect.

A : measurement of q are done for defined (α, β,ϒ) : centres to centres angles
B, C : measurement of q are done for angles varying around (α, β,ϒ)
A, B, C conditions will yield to different measured q values, A giving the true value, the measurand obtained in B and C conditions is equal to the true value plus a systematic error (not randomized).

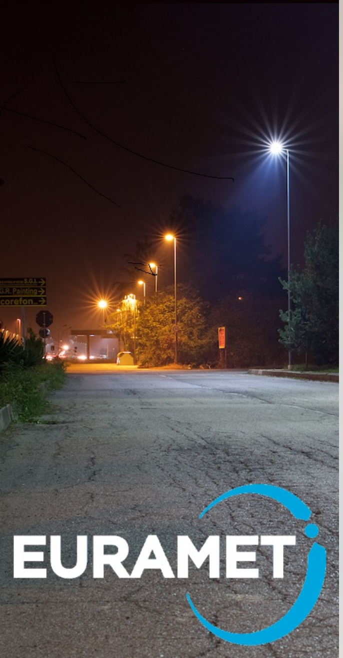
Impact of optical systems characteristics for illumination and detection : simple examples



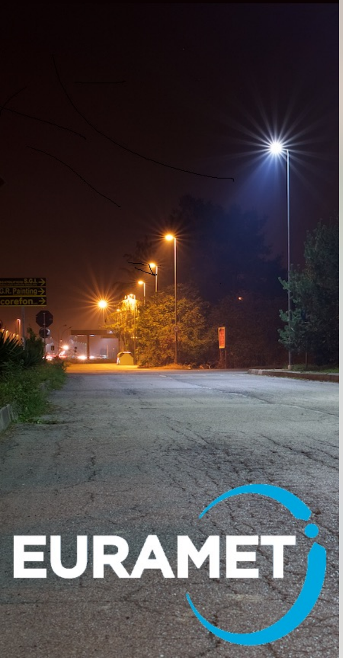


Laboratory and portable (in-situ measurement) goniometers have numerous optical setups, requiring to consider many cases.

But optical systems characteristics for illumination and detection can sorted in two categories : (1) collimating and telecentric systems (defined by beam divergence) and (2) imaging or flat collecting/emitting areas (defined by FOV and aperture).



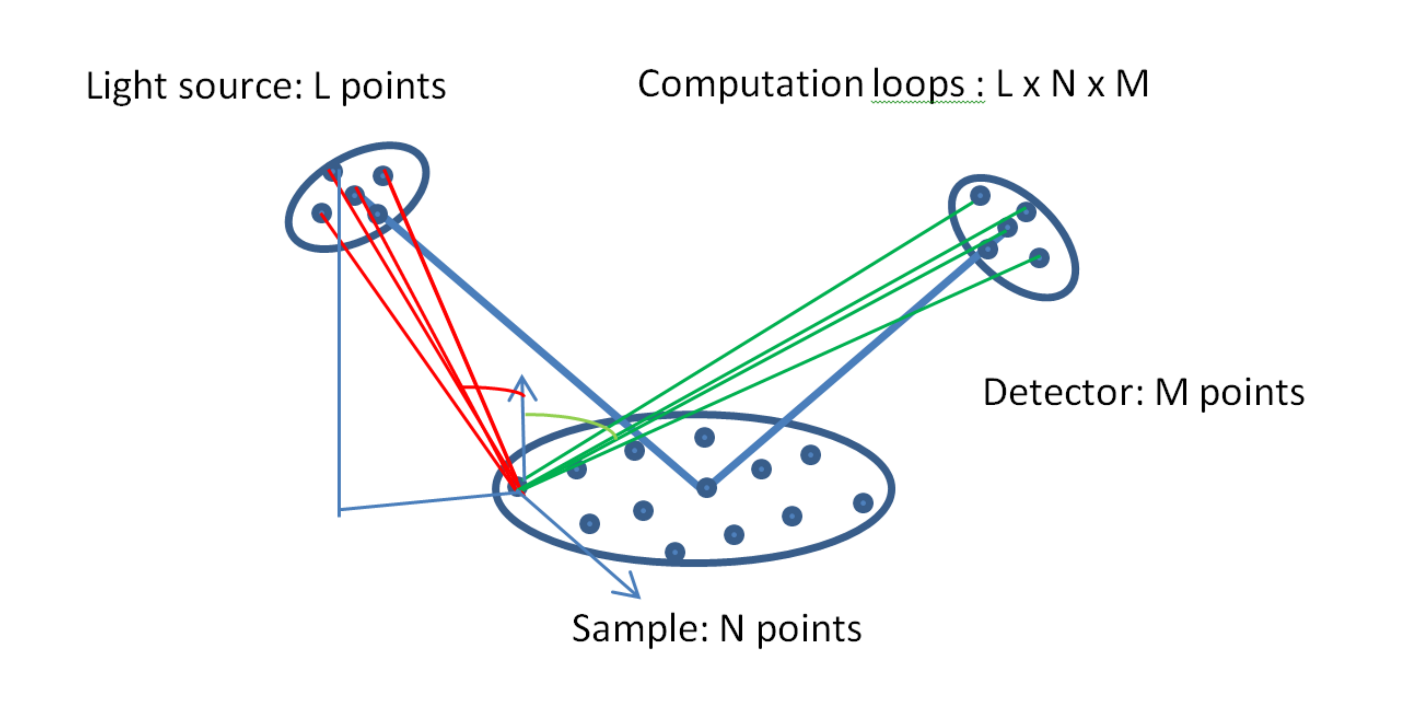
Computer calculation of the systematic error related to geometrical characteristics



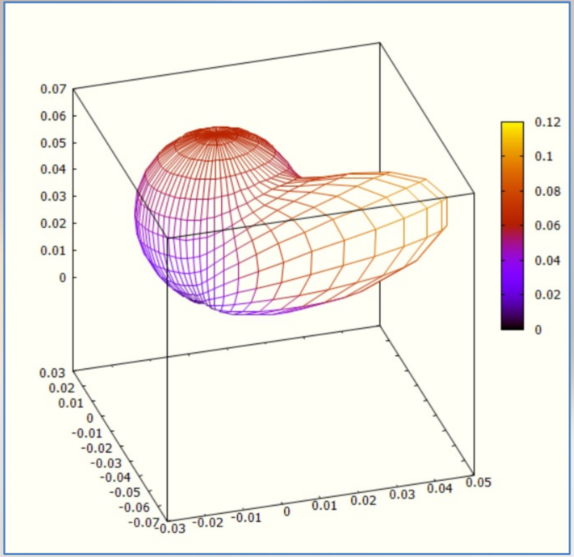
Approach :

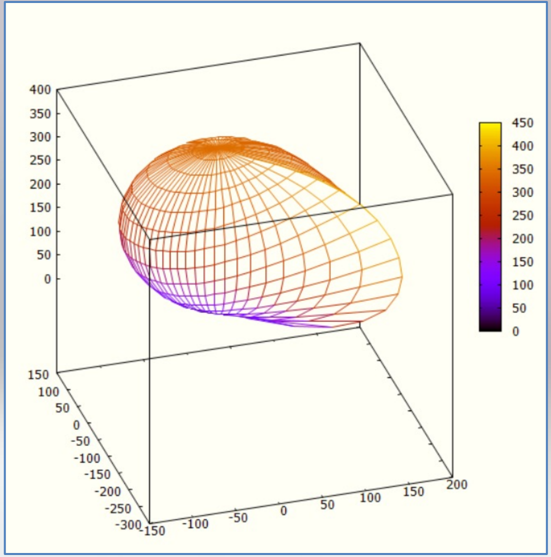
- The reflection angles on the sample are defined by the illumination ray direction and the detection ray direction, each ray is represented by a starting point and an ending point belonging either to the emitting area, or sample area or detection area, these areas are delimited by FOVs and apertures.
- Averaging the luminance coefficient for all possible points over the illumination area, sample area and detection area will provide the actual measurand with a systematic error.
- If a reflection model is given the error can be calculated as the difference between the true value and the estimated measurand by the averaging process.

Computation : integration



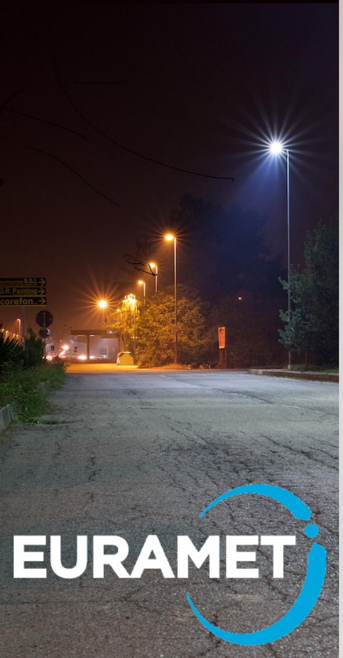
BRDF models





Left : Lambertian and Phong (specular) combined components

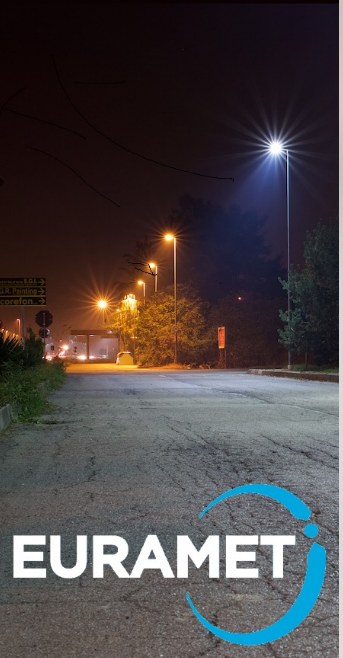
Right : simulation of C2 by the software (with the experimental component)

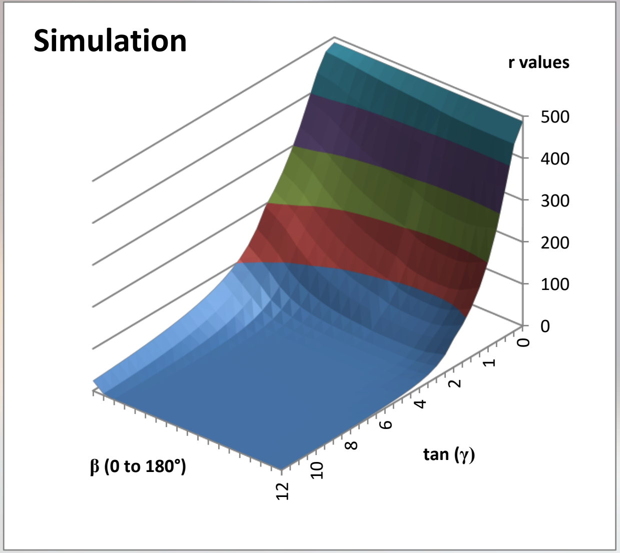


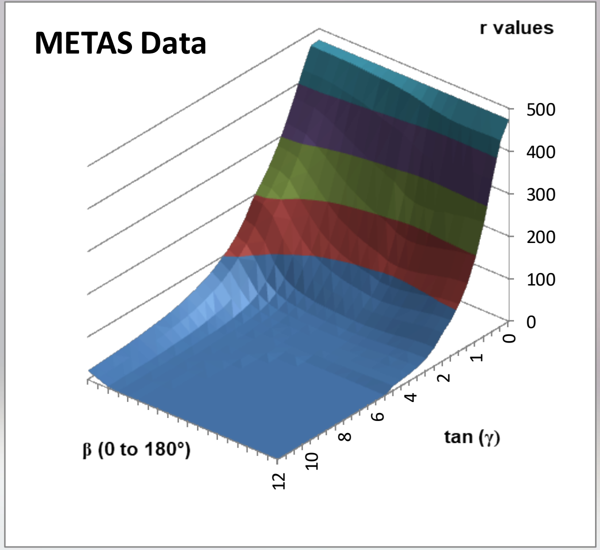
Computer calculation of errors related to geometrical characteristics

- The reflection model must be close to the sample for which we want to determine a measurement uncertainty, but also the way the data model are obtained must be fast enough to enable averaging over an huge number of points in an acceptable time.
- A parametric mathematical BRDF model has been successfully implemented for five samples of different specular coefficient, S1 values : 0.25, 0.39, 0.93, 1.11, and 1.49.
- To increased the speed – a high resolution (0.1°) 3D lookup table of the model is precomputed, then the luminance coefficient is linearly interpolated for

Modelling road samples (example measured at METAS)

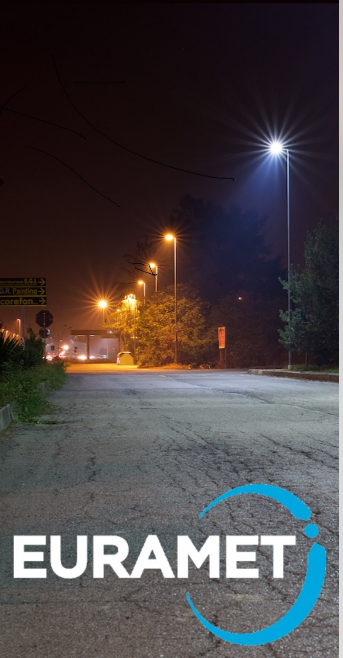






Example of a fitted r-table under Excel spreadsheet. Difference on r-table is 3% of the maximum value. The five model references have been fitted with deviation less than 10% of maximum from original r-tables.

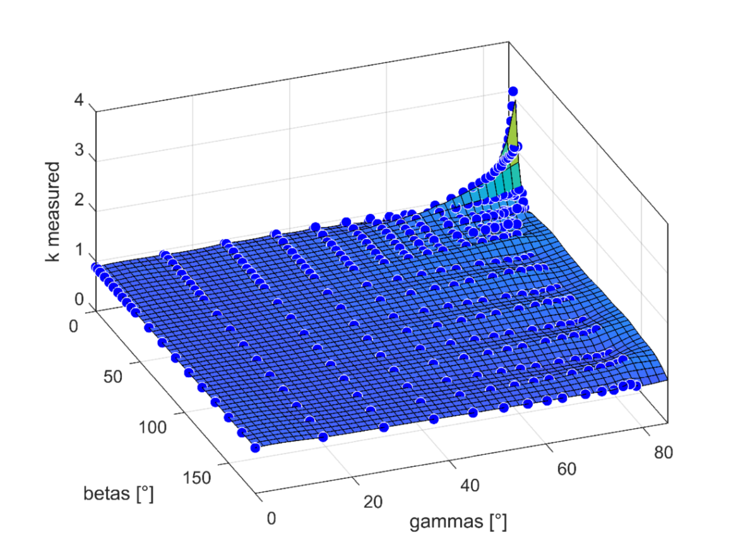
Model details (excerpt from the related paper's draft)



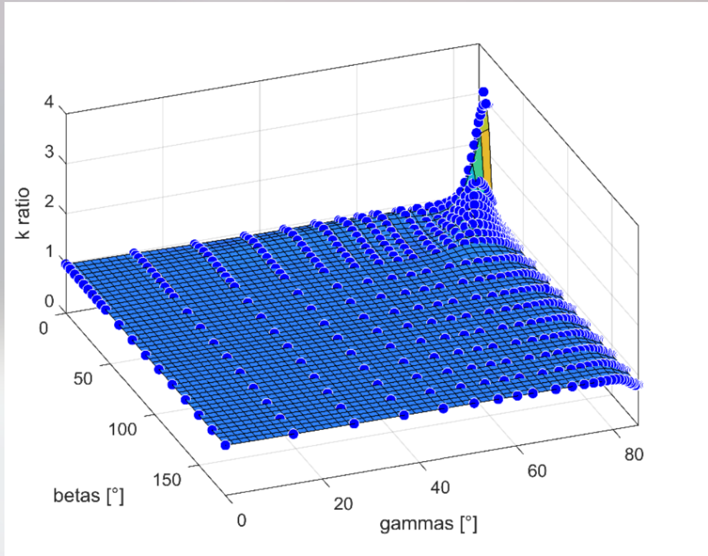
Model components	Mathematical expression	Parameters
diffuse (constant)	k_{diff}	
scattered specular (Phong model) [14]	$k_{phong} \cdot (\cos\Omega)^r$	$\cos\Omega = \cos\theta i \cdot \cos\theta r - \sin\theta i \cdot \sin\theta r \cdot \cos(\varphi i - \varphi r)$ $\theta i, \theta r$ polar incident and reflected angles, equal to 0 at zenith and $\leq \pi/2$ $\varphi i, \varphi r$:azimuthal and reflected angles, φ of detector centre is 0
experimental based on an artificial function of (ε,β)	$k_{exp} \cdot f(\varepsilon)^q \cdot \left(\frac{\pi - \beta}{\pi}\right) \exp(1 + q \cdot f(\varepsilon)^z)$	$\varepsilon = \theta i \cdot \theta r / \theta r^*$ $\beta = \lvert \varphi i - \varphi r - \pi \rvert$ $f(\varepsilon) = \sin\varepsilon \cdot \frac{\cos\varepsilon}{(\cos\varepsilon)^2 + \mu}$
global attenuation factor for grazing angles of incidence or observation	$g(\theta i) \cdot g(\theta r) / g(\theta r^*)$	$g(\theta) = \begin{cases} (a \cdot \theta^2 + b \cdot \theta + c)^t, & \text{for } \theta > \theta_l, \\ g(\theta) = 1, & \text{for } \theta < \theta_l, \quad \theta_l > 85.3° \end{cases}$ θr^* :polar observation angle of fitted r-tables (89°)
scattered retro-reflected (modified Phong model)	$k_{phong-retro} \cdot (\cos\Omega')^s$	$\cos\Omega' = \cos\theta i \cdot \cos\theta r + \sin\theta i \cdot \sin\theta r \cdot \cos(\varphi i - \varphi r)$

Note: all parameters are variable and adjusted to match the targeted reference, except the value of μ of the function f which is a constant.

Comparison with experimental results (provided by METAS –NMI of Switzerland – R3 plate)

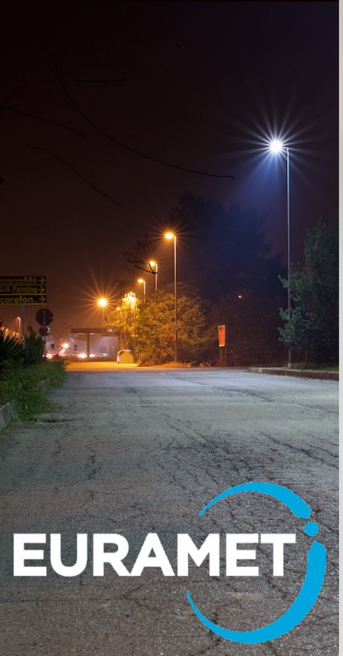


Ratio between measured *r*-tables MoFOR/LaFOR



Ratio between soft results MoFOR /LaFOR

Note : the software uses the CIE R3 table, the experimental data were obtained with a physical reference plate R3, differences between the sample has not been studied.



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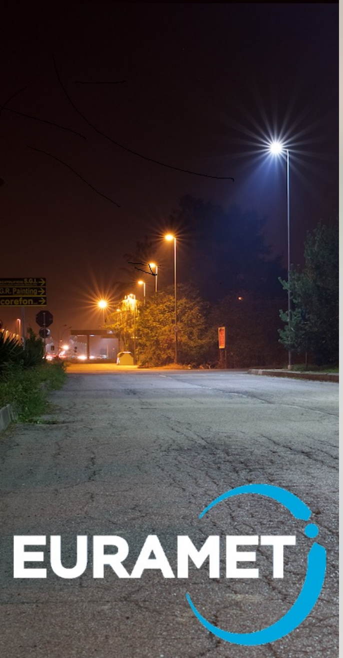
Accounting of angles uncertainties in geometrical effects



- Sample’s misalignments and positioning errors, of random nature, bring also contributions from the uncertainty on angles. Misalignments of sample change the effective illumination angles and the detection angles.
- Systematic errors due to angle’s integration and uncertainty on angles, including sample’s misalignment, must be computed all together and only a Monte Carlo Method (MCM) is easily implementable. For each draw an integral must be computed with the input angles represented by their distribution and modified by misalignment also represented by distributions (next slide)
- To gain time an approximation of BRDF based on a 2nd degree polynomial, derived from 3 integrations, is used for each independent angle variation, this function is used in place of the integral computation (see appendix I)

Monte Carlo Method – GUM supplement 1

a) *Formulation*:

1) define the output quantity Y, the quantity intended to be measured (the measurand);

2) determine the input quantities $\boldsymbol{X} = (X_1, \ldots, X_N)^\top$ upon which Y depends;

3) develop a model relating Y and $\boldsymbol{X}$;

4) on the basis of available knowledge assign PDFs—Gaussian (normal), rectangular (uniform), etc.—to the X_i. Assign instead a joint PDF to those X_i that are not independent;

b) *Propagation*: propagate the PDFs for the X_i through the model to obtain the PDF for Y;

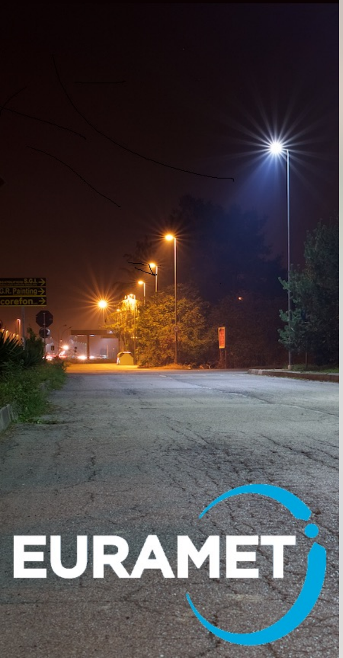
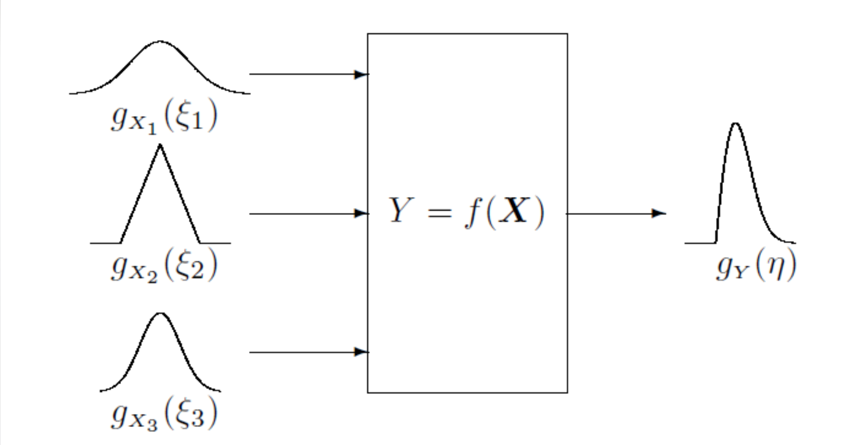
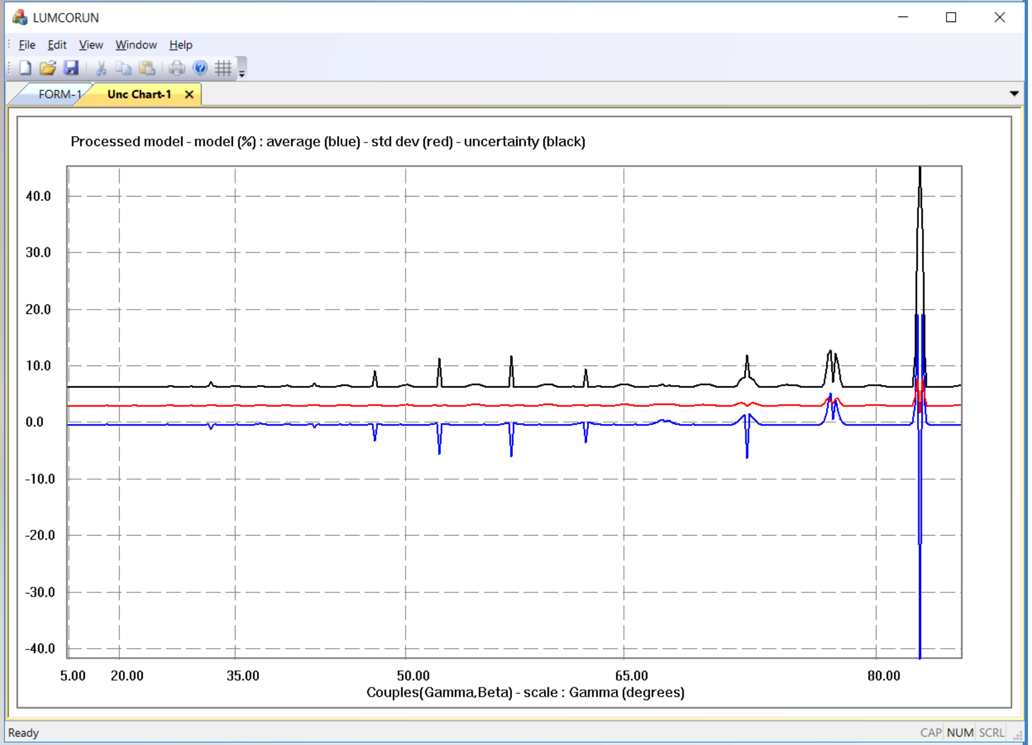


Figure 2 — Illustration of the propagation of distributions for N = 3 independent input quantities



Examples of results from the software



Goniometer sampling :

- Gama : 5°, Beta = 10° , 369 points

Distances

- Sample - detector: 500 mm
- Sample – light source: 500 mm

Diameters

- Sample Illumination size: diam. 50 mm
- Light source: diameter (8 mm)
- Detector size: diameter (8mm)
- Sample detection size diam. 50 mm

Spatial Sampling

- Area sampling: 2 mm

Angles uncertainty and sample misalignment

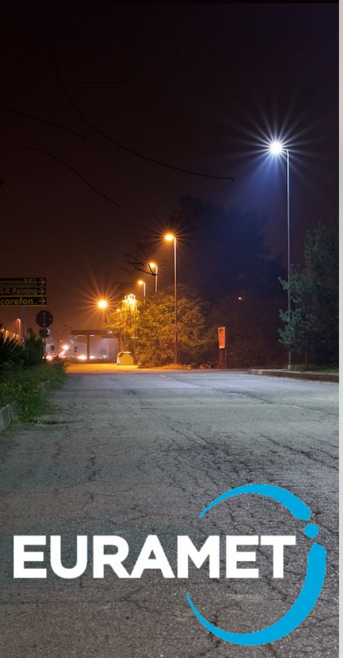
- standard uncertainty 0.2° - distribution : uniform

Simulation sample :

- METAS sample

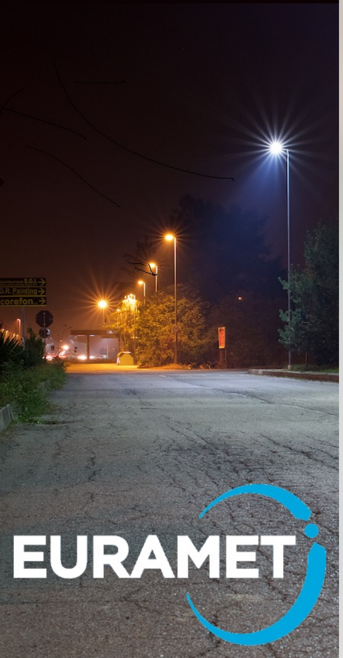
Computation time = 35 s

MCM : 5000 trials



The blue trace is the systematic error due to the integration, the red trace is the standard deviation of this integration and the black trace is the extended uncertainty .

Programme demonstration



End of slides, screen is switched to the programme window for demonstration.

Appendix 1 : MCM approximation (JCGM 100)

Combination of uncertainties

$$u_c^2(y) = \sum_{i=1}^{N}\left[c_i u(x_i)\right]^2 \equiv \sum_{i=1}^{N} u_i^2(y) \qquad (11a)$$

$$u_c^2(y) = \left[\sum_{i=1}^{N} c_i u(x_i)\right]^2 = \left[\sum_{i=1}^{N} \frac{\partial f}{\partial x_i} u(x_i)\right]^2 \qquad (16)$$

NOTE 2 The combined standard uncertainty $u_c(y)$ may be calculated numerically by replacing $c_i u(x_i)$ in Equation (11a) with

$$Z_i = \frac{1}{2}\left\{f\left[x_1, \ldots, x_i + u(x_i), \ldots, x_N\right] - f\left[x_1, \ldots, x_i - u(x_i), \ldots, x_N\right]\right\}$$

That is, $u_i(y)$ is evaluated numerically by calculating the change in y due to a change in x_i of $+u(x_i)$ and of $-u(x_i)$. The value of $u_i(y)$ may then be taken as $|Z_i|$ and the value of the corresponding sensitivity coefficient c_i as $Z_i/u(x_i)$.

$c_\alpha.u(\alpha)$ is computed using I(α-δα), I(α), I(α+δα) to derive a 2nd degree polynomial p(α) , δα is adjusted according to α distribution:

$c_\alpha.u(\alpha)$ = standard deviation of p(α) for n draws of α.

This is done for (α, β,ϒ) and the two misalignment angles and then combined using 11a.