System analysis of ILMD-based LID measurement systems using Monte Carlo simulation

Markus Katona[1], Klaus Trampert[1], Cornelius Neumann[1], Christian Schwanengel[2]

[1]*Karlsruhe Institute of Technology, Karlsruhe, Germany,* [2]*TechnoTeam Bildverarbeitungs GmbH, Ilmenau, Germany*
Corresponding e-mail address: markus.katona@kit.edu

ILMD- (Imaging Luminance Measuring Device) based LID measuring systems, are an established method for measuring the luminous intensity distribution (LID) of light sources in the far field. The advantage of this system is the high-resolution acquisition of a large angular range with one image. For the uncertainty budget, the mathematical description of the system can be divided into a photometrical and a geometrical component. For the uncertainty analysis, the measurement and calibration process are simulated by Monte Carlo method. Here we present the geometrical system description based on kinematic transformations. An analysis of the geometrical input parameters is shown.

INTRODUCTION

The LID $I(\varphi,\vartheta)$ is the luminous flux Φ per solid angle Ω that is emitted in the direction (φ,ϑ). To assume the light source (Device under test: DUT) as a point source, the measurement distance is large compared to the DUT dimensions. A common method to measure the LID, is the ILMD measurement system [1]. For this method, a DUT is mounted on a goniophotometer and illuminates a white screen in a large distance (see fig. 1), and the luminance on the screen is measured by an ILMD.

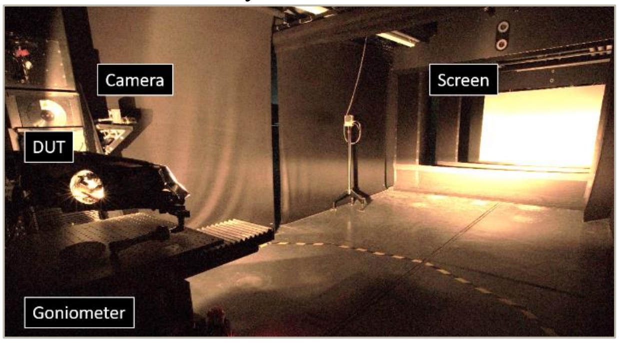

Figure 1: ILMD-based LID measuring system.

Knowing the geometric relation between the system components, the LID in the angular range of the screen can be calculated. If the interesting angular range of the LID of the DUT is larger than the screen, the goniometer rotates the DUT in multiple viewing directions, so that the full range is seen by the screen. These LID segments are then stitched together with an image-merging algorithm [2]. To determine the uncertainty budget of this system, a Monte Carlo simulation is useful.

SENSITIVITY ANALYSIS

For the sensitivity analysis, according to GUM, a good mathematical description of the system is essential. For the following uncertainty analysis, we separate the LID into its geometric flow and the photometric flux component. We analyse the geometric component and combine a LID with high gradient.

To analyse the geometric flux, we simulate the light path from the DUT to the measuring screen, considering the rotation of the DUT by the goniometer. The geometrical system description is based on kinematic methods from robotics. In case of rotation of the DUT, both static and moving system components have an influence on the measurement uncertainty. Here, for example, geometric deviations between the photometric center of gravity of the DUT and the center of rotation of the goniometer have an impact. Other factors are the skew of the goniometer axes and the distance between the goniometer and the measuring screen.

KINEMATIC SYSTEM SETUP

Kinematics usually describe the motion of robots by representing the relation between moving parts and the position of the robot. Every moving system can be described by a chain of fixed and free translations t and rotations R in homogeneous coordinates [3]. The transformation

$$X_{i+1} = T_i * X_i \qquad (1)$$

describes the transfer of position and orientation of the coordinate system X_i to X_{i+1} with the transformation matrix

$$T_i = \begin{pmatrix} R & t \\ 0\,0\,0 & 1 \end{pmatrix} = \begin{pmatrix} R(\theta_x,\theta_y,\theta_z) & t(x,y,z) \\ 0\,0\,0 & 1 \end{pmatrix} \qquad (2)$$

By combining multiple transformations, the total transformation matrix can be described as:

$$T_{total} = T_{\mathrm{n-1\to n}} * \ldots * T_{1\to 2} * T_{0\to 1} \qquad (3)$$

To analyse the geometric uncertainty of the ILMD LID measurement system, we define a coordinate system for every critical system component. The associated chain is shown in fig. 2.

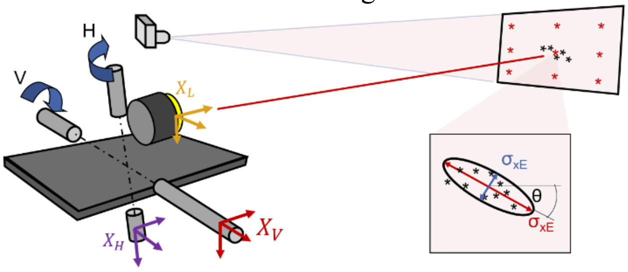

Figure 2: System components and coordinate systems for geometric calibration.

The light source X_L, is somewhere mounted on the goniometer table. The goniometer rotates the light source around the horizontal goniometer-axis X_H that is skewed and shifted to the vertical goniometer-axis X_V. Then the goniometer rotates around the vertical axis that is skewed against the optical axis and is in a measurement distance to the screen X_S. The full transformation matrix for the ILMD LID measurement system is given by

$$T_{total} = T_S * T_{V,pose} * T_{V,act} * T_{H,pose} * T_{H,act} * T_L \quad (4)$$

Note that the transformation of the goniometer-axis coordinate system has a fixed part "pose" that describes an offset and a moving part "act" that describe the goniometer rotation position.

MONTE CARLO SIMULATION

The measurement uncertainty analysis of the system was carried out with a Monte Carlo simulation. The calibration of the geometric relationships was assumed to be ideal. The necessary translation, and rotation parameters of the goniometer, were measured separately. A compact budget of the parameters is shown in tab 1. We assume, for example, that the test object is placed on the goniometer with an uncertainty of 1 mm in each direction, which is described by the translation of T_L . To analyze the geometric uncertainty we now simulate the poses of the test object with known goniometer rotation for nine exemplary directions. They are displayed as a 3x3 point matrix on the measurement screen as shown in Fig. 2. The shown error ellipse shows the result of the MC of the mentioned input parameters with 10.000 iterations. The error ellipse of the point cloud has a large ellipse axis σ_{xE} and a small ellipse axis σ_{yE} (see Fig. 2). These axes form an aperture angle with respect to the goniometer center. Also shown is the distance ratio $\sigma_{dist} = 1 - d/d_0$ of the variation of the measuring distance DUT-screen. The measuring distance is used to convert the illuminance on the screen into luminous intensity to the power of 2.

Table 1: Used input parameter and its uncertainties for Monte Carlo simulation. All empty entrances are zero.

#	t/R		x,y,z [m] θx,θy,θz [°]			Standard deviation [mm] or [°]		
			x	y	z	σ_x	σ_y	σ_z
1	T_L	t				1	1	1
		R				0.01	0.01	0.01
2	$T_{H,act}$	R					0.0043	
3	$T_{H,pose}$	t						0.1
		R						0.05
4	$T_{V,act}$	R				0.0036		
5	$T_{V,pose}$	t			10			2
		R				0.005	0.005	0.005
6	T_S	t				1	1	

RESULTS

The overall result is shown in fig. 3 and tab. 2. This result is a first estimation of the uncertainty of ILMD LID measurement.

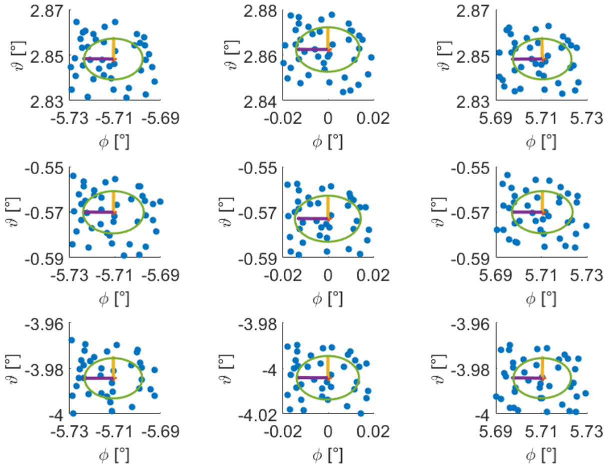

Figure 3: Visualized uncertainty results for every exemplary direction for no goniometer rotation.

These results must now be combined with the LID of the DUT to obtain the angle dependent uncertainty of the LID. The influence of the image merging method still needs to be investigated.

Table 2: Uncertainty results by number

	σ_{dist}	σ_{xE}	σ_{yE}
T_{total}	0.00023	0.01441°	0.01429°

REFERENCES

1. C. Schwanengel 2012 Comparison of Techniques for Measuring Luminous Intensity Distribution Overall and Across Segments (Germany: TechnoTeam Bildverarbeitung GmbH)
2. I. L. Sayanca, K. Trampert and C. Neumann, Indirect Light Intensity Distribution Measurement using Image Merging, AMCTM2017, Glasgow.
3. Lindemann M, Maass R and Sauter G 2015 Robot goniophotometry at PTB Metrologia 52 167–94