TechnoTeam
Bildverarbeitung GmbH

VIDEO PHOTOMETER

IMAGING LIGHT AND COLOUR
MEASURING SYSTEMS

LMK

APPLICATION OVERVIEW

Introduction

Imaging analysis of lighting scenarios and illuminated scenes are becoming more and more important. The complex analysis of various scenes requires the knowledge of the luminance distribution within the whole field of view or at least in many selected parts of it. Solving the necessary measuring tasks point by point either takes an enormous amount of time or is only possible within a coarse raster grid, if at all. Thus the development of spatially resolved radiation receivers has enabled the user to solve such measurement problems.

Some of the most important measurement tasks in which our applications are used and what one can measure with one of our LMK measurement systems are shown here:

Architectural lighting

- Luminance - Brightness level light pollution, glare sensation, visual perception
- Color, color appearance
- Luminous intensity distribution (LID), ray-data, BRDF data
- Non visual effect - blue light hazard, human melatonin suppression

Automotive lighting

- Exterior: head/tail lamps - luminance, color, luminous intensity distribution (LID)
- Interior: ambient and dashboard illumination - visibility, contrasts, visual and color appearance rating
- Display design - visual perception, glare sensation, contrast sensitivity

Lamp/Luminaire industry

- Luminance
- Color
- Luminous intensity distribution (LID) – ray data
- Non visuals – Blue light hazard

Display industry/metrology

- Luminance - brightness, uniformity, contrast ratio, image sticking, angular performance
- Color – color reproduction, color homogeneity
- Pixel defects and crosstalk
- Gamma determination and rating

TechnoTeam Bildverarbeitung GmbH

LMK

CALIBRATION PROCESS

An ILMD/ICMD (short IxMD) system consists of a digital camera, optical filters for the spectral matching, (changeable) lenses and additional neutral density filters. The aim is to measure the two-dimensional projection of the luminance / color distribution of a device under test (DUT) with or without a geometrical calibration.

For accurate data evaluation, all non-ideal properties of the system need to be corrected in relation to international agreed standards (e.g. luminance) typically using calibration factors. For this purpose, the software controlling the IxMD, needs a model and model parameters. The estimation of the model parameter is the aim of the individual adjustment of a measuring system. With the additional calibration the success of the adjustment will be checked and stated including the associated measurement uncertainty verified by the measurement of defined index values.

Most of the following measurements to estimate model parameter are made individually for every system and lens. Only viewing measurements are system specific only and can be done once for a system type.

All characterizations described with red index values are performed individually. Some other characterizations described with black index values can be created system specific in most cases.

This description is valid for an LMK COLOR camera with a focusable lens and neutral density filters.

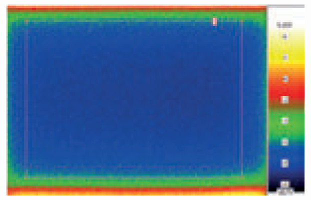
For every measurement the adjustments made by the measurement before are taken into account.

If no other reference is given all tests and characterizations are done according to DIN5032-10:2019 / CIE TC2-59 CD:2019

The way to a calibrated ILMD/ICMD system

$f_{3,0}$ Dark signal properties

Measurement and characterization of the dark signal properties of a system including dark signal, dark signal non-uniformity and faulty pixels.



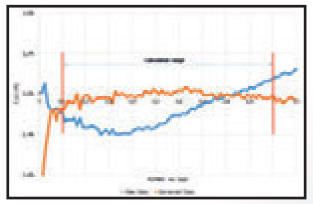
Dark signal non-uniformity (of the system without correction) at 5s integration time and 25°C ambient temperature.

Apply all the dark signal properties for correction and calculate the detection limit (relative or using a common calibration factor).

$f_{3,1}$ Basic camera and sensor data

Measurement of basic camera and sensor data (not related to lenses) using the Photon Transfer Method (PTM) to estimate the system transfer factor k_{sys}, the basic noise σ_0 and the full well capacity Q_r.

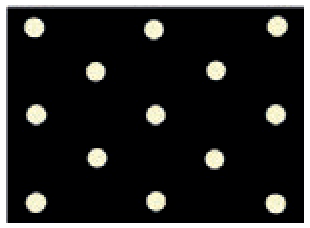
The non-linearity over different integration times with selected luminance values is measured and used for correction later on.



Measurement with and without correction of the non-linearity for a system.

f_{21}, f_{22} Lens shading

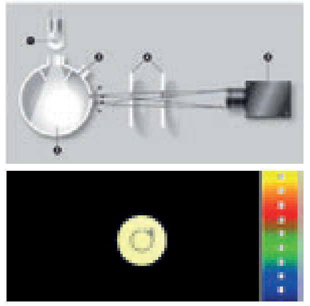
Flat field measurements with large homogenous objects using specialized integrating spheres and raster measurements using small homogenous objects and a rotation stage.



Example: Raster measurement for the characterization of the lens shading to measure the f_{22} uniformity index after using all measured corrections.

f_{Adj} Adjustment

Measure the calibration factor for every color filter and use the luminance for standard illuminant A as the reference value.



Measurement setup according to DIN5032-10 for the luminance adjustment of an ILMD.

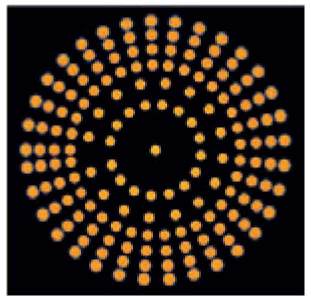
ΔC Color calibration

Measure different known light sources (LED based L³ STANDARDs or other references) and calculate a transformation matrix for the camera color space (4 to 8 filters) to the standard color space of the 2° CIE standard observer.

Multi-Color calibration with different L³ STANDARDs. Apply the transformation, perform test measurements and calculate color differences ΔC.

Lens and filter distortion correction

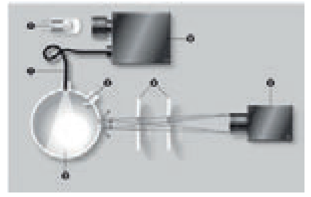
Measure the distortion caused by the color filters and/or lenses and calculate correction information.



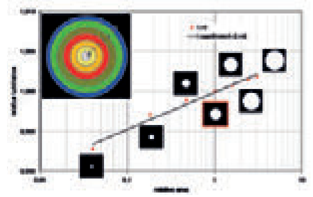
Example of a measurement grid for a sky lens (fisheye lens) to calculate the angular positions for every pixel e.g. necessary for UGR evaluation.

f_1' $f_{6,T}$ f_{12} f_{23} f_{24} f_{25} f_{29} Further characterization

After finishing all the measurements used for correction multiple characterizations are necessary to check the calibrated system:

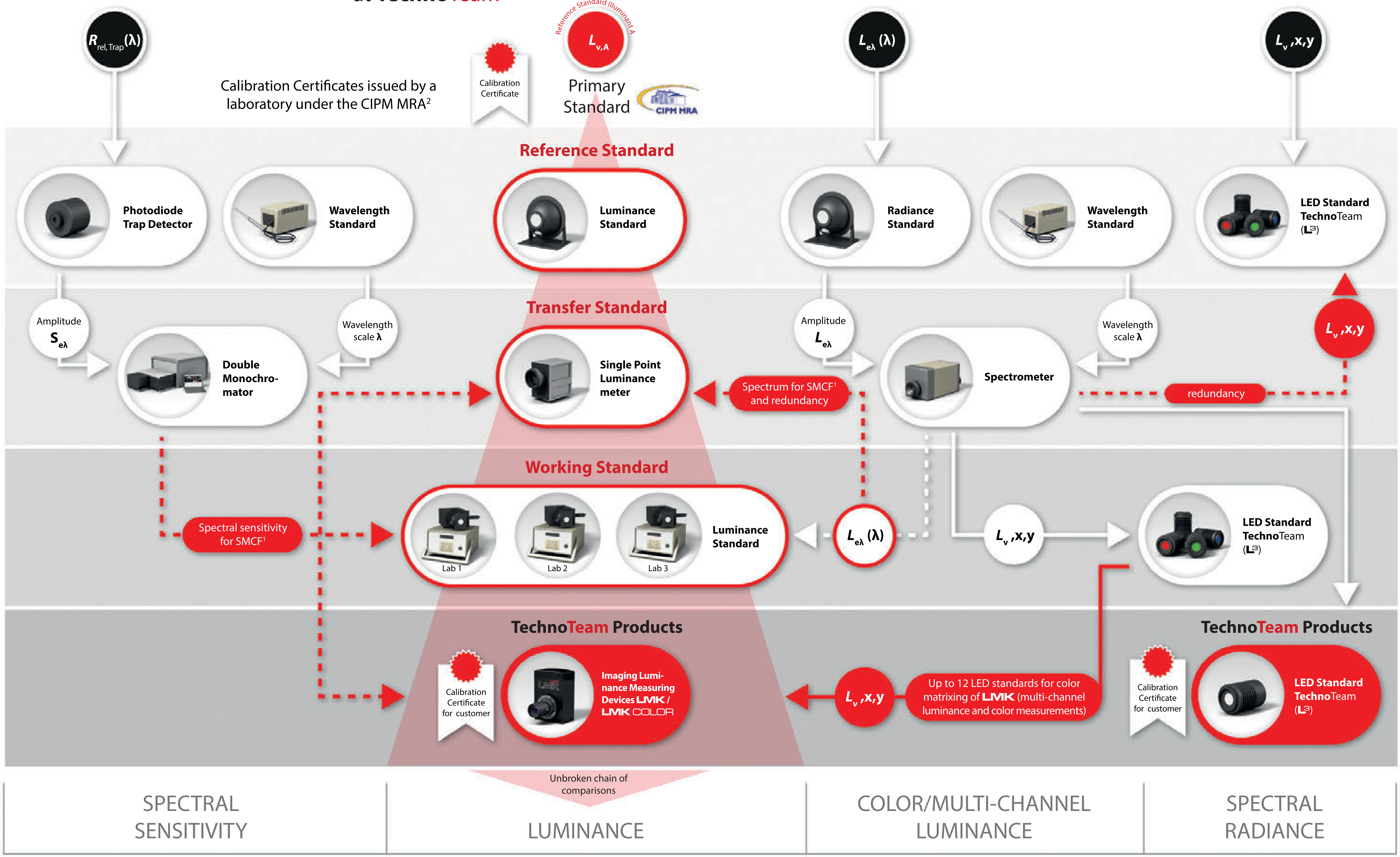


Measurement setup according to DIN5032-10 for the spectral responsivity measurement of an ILMD e.g. to state f_1'.



Example measurements results for the Size-Of-Source effect stated with the characteristic value f_{29}

TRACEABILITY
at TechnoTeam



1 SMCF – spectral missmatch correction factor | 2 The CIPM MRA has been signed by the representatives of 105 institutes – from 59 Member States, 42 Associates of the CGPM, and 4 international organizations – and covers a further 157 institutes designated by the signatory bodies. The most important institutes for us are PTB and METAS actually.

LMK6

The **LMK**6 is at the center of the entire **LMK** product family with a photopic glass filter to adapt the system to the V(λ)- function or a set of full filter glasses to realize the matching to the 2° CIE standard observer.

It's robust construction, compact dimensions and lightweight means that it can be used in almost every environment and process for a wide range of light measurement tasks.

In conjunction with our versatile software, a wide array of applications where imaging determination and evaluation of luminances can be addressed.

A large selection of high-quality standard lenses and special imaging systems in combination with an interchangeable lens mount further increase the flexibility of the **LMK**. As a result, the **LMK** is able to meet any light mterology challlenge by combining a wide variety of measuring devices in one system.

Modulation detection (e.g. flicker)

By utilizing CMOS image sensor arrays, it is not necessary to transfer a complete image during image acquisition. Rather, CMOS technology makes it possible to read if desired, only parts of the image data. For example, individual image pixels or image lines can be recorded.

With a special modulation measurement the **LMK**6 is able to measure the modulation frequency of the light source. Using this information the influence of the modulation frequency to the measurement result can be minimized.

Trigger function

The **LMK**6 series has both an external and an internal trigger function to communicate with its operating environment. Thus the **LMK**6 is able to state the integration time with respect to an external signal.

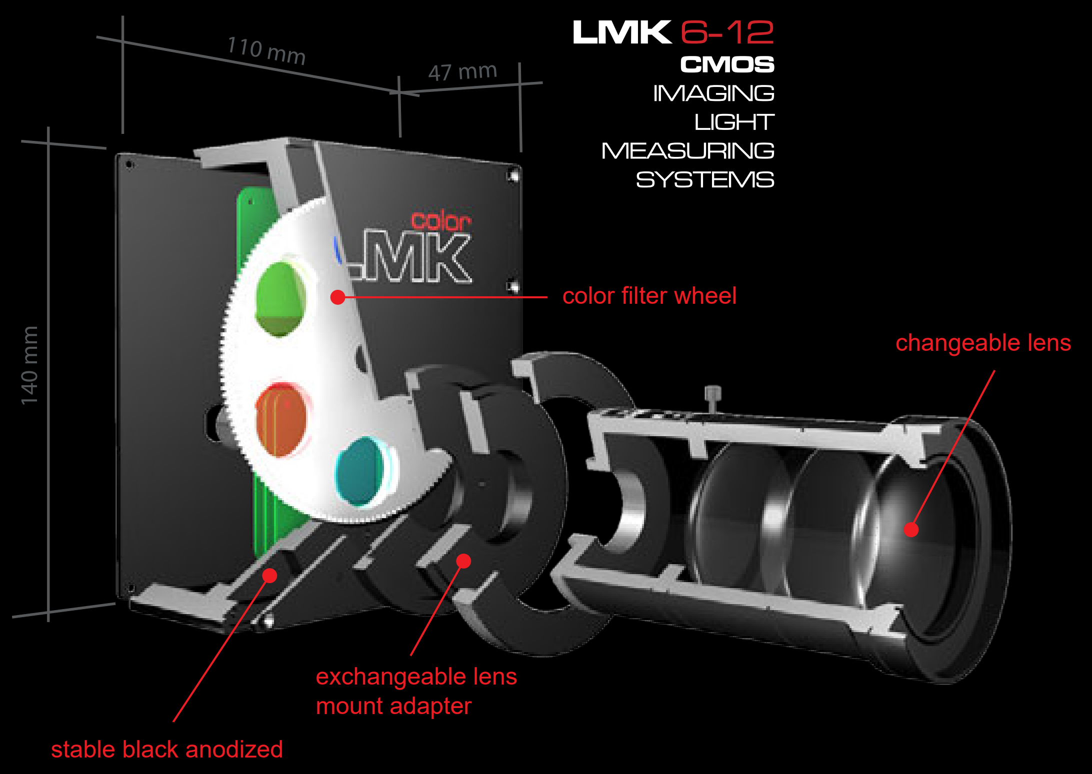
Image capture can be controlled from an external trigger source. Also an external source can be controlled by the **LMK**6 itself.

For both cases time delays before and after the image integration are possible. This avoids the need for expensive external power / trigger supplies.

LMK

SPECIFICATIONS

Camera model	housing dimensions (HxWxD)	weight (without lens)	available lenses (approx. weight)
LMK 6 MONO	80 mm x 80 mm x 47 mm	600 g	120 g - 800 g
LMK 6-5 COLOR	117 mm x 90 mm x 47 mm	800 g	120 g - 600 g
LMK 6-12 COLOR	140 mm x 110 mm x 47 mm	1300 g	200 g - 800 g



Standard resolution **LMK** 6-5 color	2464 x 2056 Pixel | Sony-CMOS [IMX 250 (2/3"); 12 Bit digital]
High resolution **LMK** 6-12 color	4112 x 3008 Pixel | Sony-CMOS [IMX 253 (1.1"); 12 Bit digital]
Measurement time	starting with 1 sec. up to 15 sec. depending on luminance level, adjusted lens and exposure/integration time
Dynamic range	[1:10000000 (~140 dB)]
Data interface	Gigabit Ethernet Interface(GigE®)
Spectral matching	using V(λ)-function matched full glas filter for luminance measures adapted with full glass filters to the X(λ)-, V(λ)- and Z(λ)-function to measure color values further full glass filters for the functions V'(λ)-, S_{mel}(λ) and BLH (blue light hazard) as well as NIR filters are available
Metrological specifications	V(λ) [f_1' < 4 %[1]]; X(λ) [f_1^* < 4 %] Z(λ) [f_1^* < 6 %]; V´(λ) [f_1^* < 6 %]
Measuring quantities	Luminance: L (cd/m²)
Chromaticity coordinates	x,y
Supported colour spaces	RGB, XYZ, sRGB, EBU-RGB, User, Lxy, Luv, Lu'v', L*u*v*, C* h* s* uv, L* a* b* , C*h*ab, HIS, HSV, HSL, WST
Measuring range (integration time)	100 µsec. ...15 sec.
Measuring range[2] depending on lens aperture value (F) mono	1 msec. ...appr. 1800 cd/m² & 3 sec. ... appr. 0.6 cd/m² (F = min.) 1 msec. ...appr. 60000 cd/m² & 3 sec. ... appr. 20 cd/m² (F = max.)
Measuring range[2] depending on lens aperture value (F) color	1 msec. ...appr. 7500 cd/m² & 3 sec. ... appr. 2.5 cd/m² (F = min.) 1 msec. ...appr. 60000 cd/m² & 3 sec. ... appr. 20 cd/m² (F = max.)
Measuring range[2] for the standard preset lens aperture value (F)	1 msec. ... ca. 10000 cd/m² & 3 sec. ... ca. 3.3 cd/m² (F=4)
Calibration uncertainty[3]	fix focused lenses ΔL [< 2 %] focusable lenses ΔL [< 2.5 %]
Repeatability[4]	ΔL [< 0.1 %]
Measuring accuracy	ΔL [< 3 % (for standard illuminant A)]
Uniformity	ΔL [< 2 %]

1 Measurements according to DIN 5032 Part 6/CIE Pub. 69 | 2 The given values representig the highest luminance values with the given setting. | 3 Calibration according to DIN 5032 Part 6 using a luminance standard led back from the Physical-Technical Federal Institute | 4 Measurement performed on a stabilized white LED light source L=100 cd/m². Mean value over 100 Pixel; repeatability

Camera lenses	TT 6.5mm focusable	TT 8mm focusable	TT 12mm focusable	TT 16mm focusable	TT 25mm focusable	TT 50mm focusable	TT 80mm focusable	TT 150mm focusable	TTmacro 2.0/36/35	TTmacro 1.5/40/35	TTmacro 1.1/56/40	TTmacro 0.8/93/50	TTmacro 0.7/126/60	TTmacro 0.5/166/60	TTmacro 1.1/130/80	TTConoscope	TTFishEye	TT-NED
Reproduction scale	-	-	-	-	-	-	-	-	2	1.5	1.1	0.8	0.7	0.5	1.1	-	-	-
Focal length [mm]	6.5	8	12	16	25	50	80	150	35	35	40	50	60	60	80	-	-	50
Distance object – front lens [mm]	-	-	-	-	-	-	-	-	36	40	56	93	126	166	130	-	-	Distance object – Lens entrance pupil appr. 14mm
Distance object – camera front plate [mm] - **LMK** 6-5	> 300	> 300	> 300	> 300	> 230	> 280	> 300	> 1100	142	134	155	192	237	265	311	180	> 300	-
Distance object – camera front plate [mm] - **LMK** 6-12	-	> 155	-	> 200	> 260	> 425	-	-	142	134	155	192	237	265	311	180	> 300	-
Object field size **LMK** 6-5	68° x 53.8°	57.5° x 44.9°	40.1° x 30.8°	30.7° x 23.3°	19.9° x 15.5°	10° x 7.6°	6.3° x 4.7°	3.3° x 2.5°	3.3 x 4.5mm²	4.5 x 5.7mm²	5.9 x 7.8mm²	8.6 x 11.5mm²	10 x 13.4mm²	14.4 x 19.2mm²	6.3 x 8.4mm²	120° (circular)	180° (circular)	15° (horizontal)
Object field size **LMK** 6-12	-	83° x 67°	-	48° x 36°	31° x 24°	16° x 12°	-	-	7.3 x 5.1mm²	9.0 x 6.5mm²	12.8 x 9.3mm²	17.6 x 13.2mm²	20.8 x 15.0mm²	30.0 x 22.0mm²	13.0 x 9.5mm²	120° (circular)	180° (circular)	15° (horizontal)

LMK DISPLAY

The characterization of different display types - small mobile phone displays up to large TV displays or also head-up displays - is an important topic in various R&D applications and the quality management for production accompanying processes.

For example automotive displays and their very strict performance, quality, and safety requirements or the measurement of virtual displays (VR/AR, ocular systems) are becoming more and more critical.

Imaging Luminance and Color measuring devices (ILMD/ICMD) can be used to analyse a various range of performance and quality benchmarks for the different display types.

The image measurement technology can be used to evaluate uniformity parameters like black-level gradients in a few seconds of measurement time. Using special lenses (e.g. hyper-centric lens (Conoscope) or Macroscopic lenses) the user can perform angular luminance and color characterisation for small parts of the display or for single pixel / subpixel structures.

Utilizing the spatial resolution, the EOTF (Electro-optical transfer function) and the Gamma can be evaluated fast or spatially resolved. The same is true for the automated evaluation of Image sticking according to different established measurement methods.

All methods include the presentation of all raw data, deduced datas and the final measurement merits to enable both, a fast check and detailed analyses.

With the Template-Image generator the presentation of several customizable test images or user-defined images is possible to customize your own evaluations. Further, automated user defined evaluations are supported by a well documented ActiveX Interface of LABSOFT. This allows automation via 3rd party applications such as LABSOFT, Matlab or C++.

The **LMK** LUMINANCE/COLOR system can be equipped with various different lens types for the display analysis. For example:

- 50mm focusable lens (whole screen analysis like uniformity measurement)
- Conoscopic lens (angular dependent luminance and color measurements)
- Macroscopic lens (single-/subpixel structure analysis e.g. for Pixel-Crosstalk analysis or the evaluation of anti-glare and anti-reflection coatings)

Target application for Research & Developement (R&D) and production controll

- Various topics in the application of display evaluation (human machine interface (HMI) displays, Head-Up display (HUD), AR/VR displays) such as luminance level, color settings, luminance/color uniformity and angular dependence of luminance/color
- Material evaluation (e.g. Brightness enhancement foils, Combiner windows for HUD)
- Evaluation of display screen surfaces (anti reflection / anti glare coatings)

LMK BlackMURA

BlackMURA supplies the analysis of selected display quality aspects according to the Uniformity Measurement Standard for Displays published by the German Automotive OEM Work Group Displays and the DFF. Thus the package provide an extension to the functions of the **LMK** LABSOFT for realising the camera alignment, a standardized non-uniformity evaluation and a gradient filter.

LMK Pixel Crosstalk

This method developed by Dr. Fink characterizes the loss of image clarity caused by anti-glare coatings. The method uses high-resolution imaging with a Macroscopic lens, giving a distribution and evaluation of scattered light.

LMK Sticking Image SI2 & SI3

Sticking Image supplies the analysis of display screen quality according to two different methods. This includes the three-level burn-in method developed by Dr. Lauer. and the two level method developed by Bauer et al.

LMK CCM

The conoscopic contrast measurement software package allows the user to perform angular contrast determination of displays easily. It provides the capability of H/V angular coordinates conversion as well as the definition of measurement regions and points in the ϑ, ϕ and ϑH, ϑV angular coordinate system.

Near Eye Display Measurement

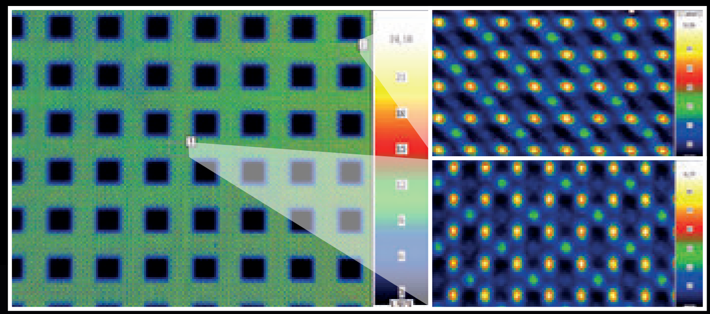
Imaging Luminance and Color Measuring Devices (ILMD / ICMD) in combination with adapted measuring lenses provide effective one-shot solutions to evaluate modern Near Eye Displays (NED). NED-suppliers asked for LMK-solutions adapted to their specific instrument structure. Here, the wide range of fields of view (FOV) and of NED-resolutions needs to be considered. On the basis of our experience in creating LMK's we offer a set of formulas to determine the basic parameters of lenses for different NED-concepts. We developed an optical system whose aperture-stop (respectively the NP (entrance pupil)) is in front of the optical surfaces. With two solutions – the conoscopic lens arrangement and special front stop lenses – we are able to offer solutions for NED measurement tasks. For highest accuracy we also can offer a robotic assisted precision aligning, scanning and rotating solution possible due to our compact camera-lens system.

Requirements of NED lenses

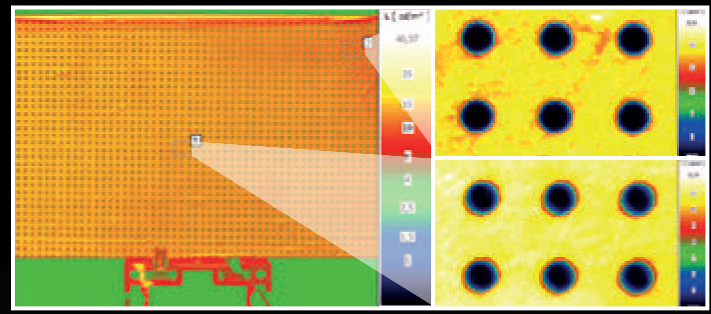
- ILMD entrance pupil has to be located inside the NED exit pupil
- ILMD entrance pupil has to be smaller than the NED exit pupil
- ILMD entrance pupil needs to be in front of the lens mechanics
- Compact luminance/color camera and lens design to enable robotic assisted precision aligning, scanning and rotation of the ILMD entrance pupil

Basic Laws of lens design

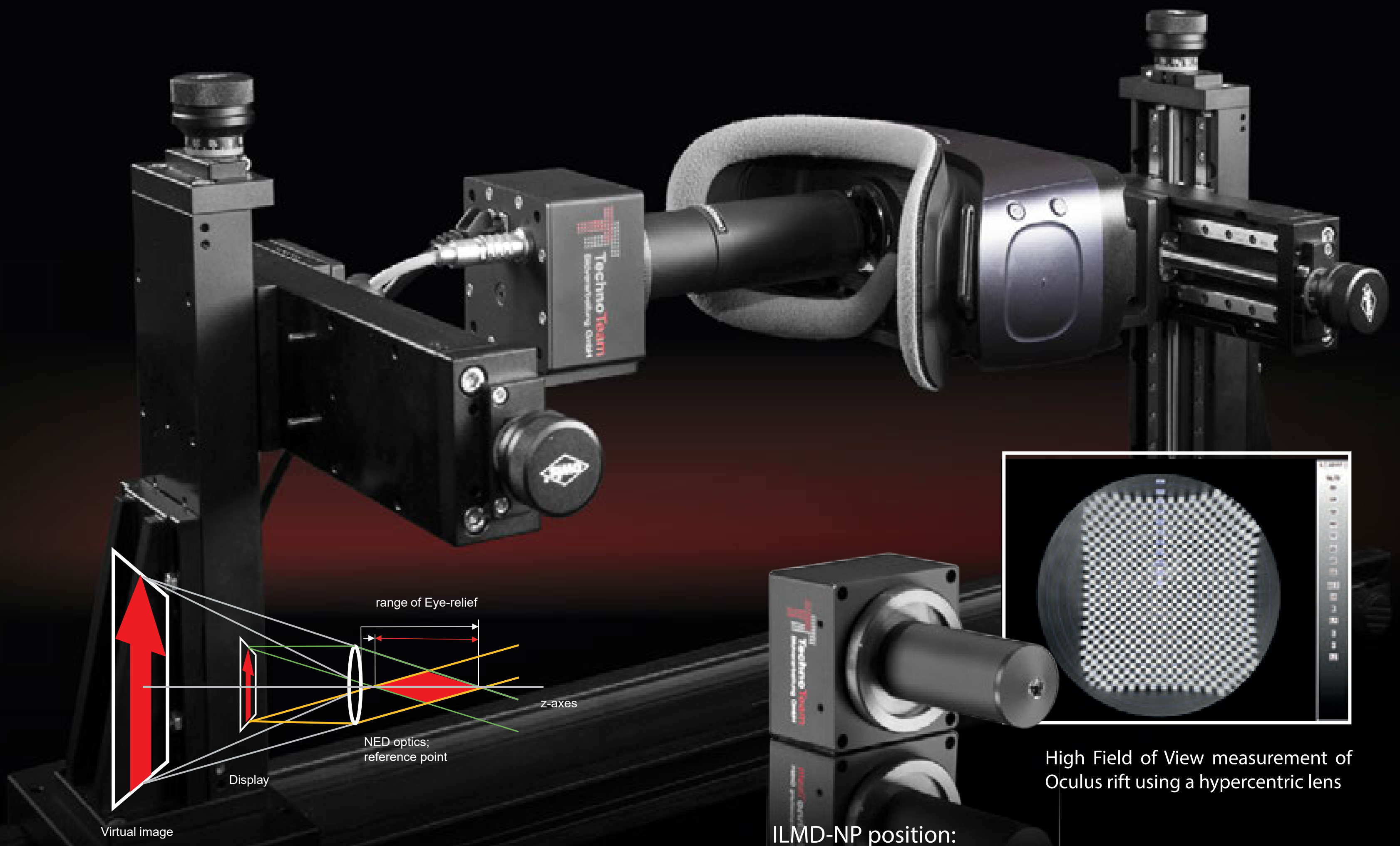
- Larger field angles require shorter focal lengths
- Larger image sensor dimensions ask for larger focal lengths to achieve a similar field angle
- High resolutions require a small field angle, or rather longer focal lengths and larger image sensors



Left: High resolution measurement of crossed line pattern of an Oculus Rift using an 50 mm ocular based front stop lens Right: Magnification of Region 2 (Top) and Region 1 (Bottom)



Left: High resolution measurement of circular reference pattern using a 50 mm ocular based front stop lens Right: Magnification of Region 2 (Top) and Region 1 (Bottom)

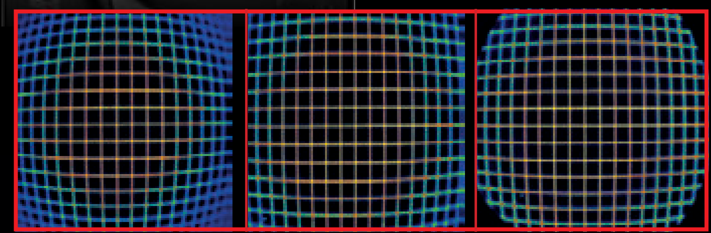


High Field of View measurement of Oculus rift using a hypercentric lens

Sensor Size	Field of View [°]	±7.5	±15	±20	±30	±40	±50	±60
1.1“	Focal length [mm]	53.8	26.5	19.5	12.3	8.45	5.95	4.10
	Resolution [CPX / °]	274	137	103	69	51	41	34
2/3“	Focal length [mm]	32.1	15.8	11.6	7.31	5.03	3.54	2.44
	Resolution [CPX / °]	163	82	61	41	31	24	20

CPX = Camera Pixel

ILMD-NP position:



Too close Correct Too far

Special front-stop lenses

Ocular lens

With the existing conoscopic lens we offer a lens that has a virtual NP (appr. 2mm diameter) in front of the lens with a special front-stop. This lens works with a real intermediate image plane. The resulting focal length of these special front-stop lenses range from 8mm up to 16mm. It can realize a captured field of view (FOV) of ±30° down to ±15°. This field of view is smaller than the nominal field of most NED designs. An ideal device under test for this would be a monocular notifying that it realizes a field angle of maximal ±30°. The diameter of the NP can be changed from 2 - 7mm.

- High resolution measurements
- Measure NED resolution, NED distortion
- Determine the NED Modulation Transfer Function (MTF)
- Other ocular based lens designs for larger-field of views possible

Conoscopic lens arrangement

Hypercentric lens

Use of a conoscopic lens means that ray bundles from an entrance pupil (app. 2mm diameter) located 2 mm in front of the first lens create an image on the image sensor which is reversed in reference to a classical LMK-lens. The conoscopic lens arrangement offers a FOV up to 120° (circular image).

- Large Field of View measurements
- Measure luminance, chromaticity and other uniformity attributes with one / few measurements
- Measure eye box properties

LMK POSITION

VISION BASED ROBOTIC

At the present time industrial robots produce a repeatability of 20-30 µm for positioning.

Comparing the robotic-controlled **LMK** with a manually positioned luminance measuring device the former has considerably better reproducibility.

An outstanding feature is the possibility of referencing the measurement positions with the use of the mounted LMK camera system. The software for the **LMK** POSITION can handle and transform both, the coordinate systems of the used optics for the **LMK** and the applied coordinate system for the device under test (DUT). Thus the software controls the robotic-arm to drive the mounted **LMK** correctly to the desired position. As a result the normal vector of the surface is determined and can be used for the orientation of the robotic hand. It offers the possibility of an easier adjustment for a perpendicular view on local reference surfaces. The perpendicular positioning or the angular-dependent orientation of the **LMK** is often a requirement for a correct measurement and with a manual positioning very complicated.

The **LMK** POSITION offers a solution for exact and automated positioning in manifold photometric and colorimetric applications.

LMK

Example Applications

Characterization of curved displays:

Detecting the device under test (DUT) using the LMK

- Direct viewing direction
- Center display in camera field of view

Measuring the geometry

- Detecting the 3D-position of the display area
- Detecting the 2D-surface of all available 3D-positions

Analyze

- Automatic, precise alignment between optical axis of **LMK** and the display surface normal of any point
- Perform measurement including conoscopic contrast, Angular Color-Uniformity etc.

Characterization of Near Eye displays:

Align the LMK

- Combine **LMK** Position with special NED Lenses
- Alignment of ILMD entrance pupil inside of NED exit pupil
- Measure for example the eye position, field of view (FOV), uniformity and the eye box
- Easy switching between left and right eye position

Automated BlackMURA setup:

Automatized and Standardized alignment of the LMK

- High precision angular alignment (axial, horizintal, vertical)
- High precision spatial alignment of surface normal and optical axis
- Moiré avoidance by defocus via distance
- Verify Distance/Lens setup by measurement field angle procedure

LMK

Presented by:

TechnoTeam
Bildverarbeitung GmbH

Werner-von-Siemens-Straße 5
98693 Ilmenau
GERMANY

Tel. +49 3677 4624 0
Fax +49 3677 4624 10

support@TechnoTeam.de

www.TechnoTeam.de