Applied Image Resolved Light- and Color Measurement Introduction and Application Examples

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Introduction

The image-resolved measurement of light and physical radiation parameters has become more and more important over the last years. The determination of image-resolved luminance and color measurements is state-of-the-art in many applications, e.g. for the night design in cars or the estimation of lighting (working environment, on roads or in tunnels).

In this paper, the authors shortly describe the fundamentals of the image-resolved luminance and color measurement technique, explaining the aims and solutions proposed for a number of application examples (lamps, headlamps, displays, switches/symbols with night design, roads/tunnels). The applications are confirmed by measuring examples.

Fundamentals of luminance and color measurement

Nowadays, luminance and color-measuring cameras are mounted on high-quality CCD digital cameras. Each of them should be correspondingly analyzed, calibrated and adapted to the respective light-measuring task. Then, the signal values found in the image can directly be converted into luminance or also color values.

As it is the case with all technical devices, also the properties of luminance- and color-measuring cameras deviate from those of ideal designs. These deviations can be grouped into systematic and stochastic components. Those deviations of the measuring values from an ideal behavior which are determined can be recorded and corrected. Whether the systematic deviations remaining after the correction are strong or not depends on the technological prerequisites, the available calibration means and on how carefully calibration is carried out. The stochastic components are signal-dependent as well as signal-independent noise. The luminance $L(x, y, \vartheta, \varphi)$ is a spatially resolved (differential) measuring quantity and, therefore, must be imaged onto the sensor. In case of sensors measuring point-to-point, the default measuring spot must be imaged, in case of image-resolving luminance meters (video-analyzers), however, the respective scene must be imaged onto the image sensor (CCD matrix). The CCD matrix being a radiation-sensitive sensor, it converts the incident radiant flux into signal charges according to their spectral sensitivity $S(\lambda)$. If the system is to measure luminances or also tristimulus values, the spectral sensitivity of the entire system must be adapted to the $V(\lambda)$-function or also to the color-matching functions $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$. For this, a filter $F(\lambda)$ or also a set of filters $F_i(\lambda)$ is used for each camera. By using the filter or also the combination of the measuring values of the set of filters, the measuring system will be adapted to the above-mentioned color-matching functions in connection with the spectral sensitivity of the respective sensor and the spectral transmission of the lens.

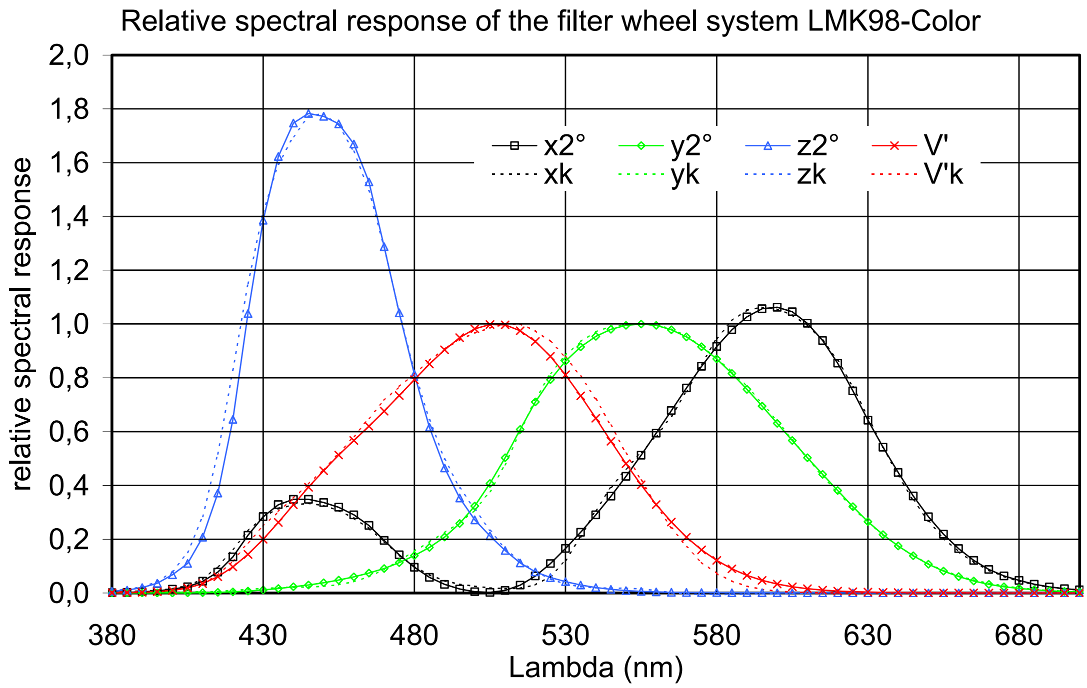


Diagram 1: Relative spectral sensitivities of an image-resolved color measuring system in comparison with the color-matching functions.

By using a measuring system which realizes the relative spectral sensitivities shown in diagram 1, it is possible to achieve a space-resolved determination of both luminances in the photopic and also in the scotopic range as well as of tristimulus values. For the spectral adaptation of space-resolving sensors, a number of problems must be considered, which are described in [1].

The system presented realizes the following spectral characteristics:

Target function	f'_1 (%)	f_1 * (%)
X2°	3,9	*3,9*
y2° / $V(\lambda)$	*2,1*	2,1
Z2°	5,4	*5,9*
$V'(\lambda)$	*6,2*	5,5

- characteristic value f'_1 see DIN5032
- characteristic value f_1 * see [2] - f'_1 without weighting with standard illuminant A)

By means of a measuring system of such kind, a great number of different lighting-engineering tasks in and around the car can be solved.

Resolution and dynamics

Essential features of a measuring device are its data resolution and the dynamic-range that can be achieved. In case of single shots, resolution is determined by the quantization of the AD converter and the noise of the signals. The resolution of the measuring values can be enhanced up to about $n_0 + (ldN)/2$ bit by averaging over neighboring pixels in the matrix (binning) or by the software (macro pixels), or also over several consecutively recorded and averaged images (multiple measurement) (N… number of averaging's (pixels, images), n_0… basic resolution of the AD-converter in bit).

Scenes which have to be evaluated from a lighting-engineering point of view are often characterized by a high dynamic range (e.g. lamps and illuminated scene together in one and the same image). The dynamic-range that can be covered by a measuring camera can be extended by a HighDyn-measurement in case of which the scene is photographed several times at different integration times. This procedure allows dynamic-ranges of 10^6 and accuracies of 10^{-2} to be achieved.

Correction of non-ideal effects of space-resolving measuring systems

When using the measuring camera for luminance or also color measurements or for determining derived lighting-engineering quantities, not only the properties of the measuring system itself (technical parameters), but also a large number of other influence factors are decisive for obtaining sufficiently exact measuring results. As it is true for all measuring systems, its inadequate use may lead to a serious misinterpretation. Therefore, it is urgently pointed out that each measuring result should be evaluated critically. Not only can the inadequate handling of the system lead to errors (here, particularly the imaging of the scene itself, i.e. blurred imaging, the measurement of too small structures, has a strong influence), but also the overall organization and layout of the scene itself are important. Thus, for example, the measuring data obtained can be influenced by an external light source or scattered light (whose strength is often underestimated) or by some instabilities such as the flickering of lamps, thus supplying only little or no information at all about the lighting-engineering parameters of the device, the installation or the scene.

With regard to the technical measuring system, the following effects must be corrected or even avoided: dark signal, non-linearity, shading of the lens, blooming, smear and blemish pixels.

In what follows, let us have a look at the scattered light as an example of those effects which have to be taken into account.

Each imaging system produces either a small or a big portion of scattered or false light. The imaging system consists of lenses or mirrors which do not only fulfill their normal functions (lenses – refraction in case of passage of light; mirrors – reflection), but present also a non-ideal behavior.

Glass-air-interfaces do not only refract the light, but also reflect it (about 4 %), whereas mirrors do not only reflect light in a directional way, but also smeared. Light can be scattered at lens mounts and diaphragms.

Thus, light will not only be transmitted from the object to those places arising from geometrical optics, but also to a number of other, unwanted places. In addition, the sensor itself has only a finite reflectivity (silicon 30 … 65 %). This means that considerable portions of the light which is imaged onto the sensor will be reflected, "wandering around the lens". All these effects produce a more or less strong "scattered light carpet".

This involves two essential measuring problems:

1. Objects large areas of which are illuminated produce a slightly higher measuring value due to the scattered light (depending on the illumination of the object field on the whole).
2. In dark areas, scattered light is measured additionally, i.e., measured contrasts are always smaller than the really existing ones (also depending on the illumination of the object field on the whole). This is of importance particularly for the assessment of negative contrasts, i.e., small dark structures on a large bright background.

Applications

The great variety of possible applications offered by the measuring systems presented are explained by means of a few examples:

Measurement of illuminated symbols (night design in the car)

The luminance, the uniformity and the tristimulus values are decisive quality criteria for assessing illuminated symbols in the night design. Based on the manual measurement using standard luminance meters (measurement of many small measuring spots), an equivalent evaluation of the classified luminance and color distribution can be performed by means of the space-resolving measuring technique. This technique permits the symbol to be recorded and evaluated by a single shot. Measurement is faster and can better be documented and used for a new evaluation at any time.

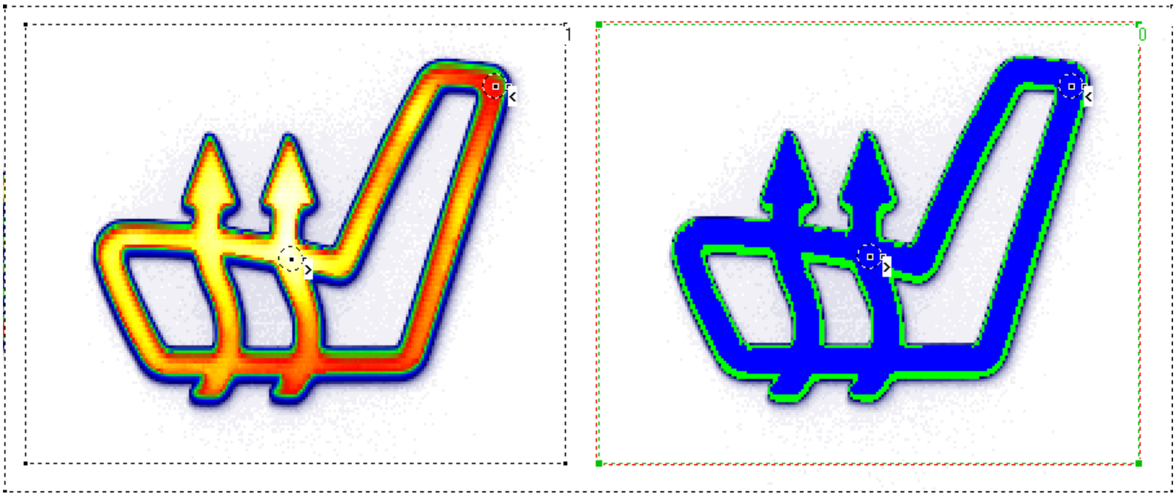


Diagram 2: Symbol and measuring regions for minimal and maximal luminance
(left-hand side: pseudocolor representation,
right-hand side: label image)

On the basis of an adaptive threshold operation, the luminous symbol can be separated from the background. In the bright area determined, the measuring values for the minimum and the maximum cannot be obtained pixel by pixel, but as an average of a small region (spot) with adjustable diameter instead. This function corresponds to an individual sensor performing ideal measurements (spotmeter) and allows stable measuring values to be calculated for the minimum, maximum and derived quantities such as contrasts. Furthermore, a number of geometrical quantities such as photometric center and the positions of the maxima and minima found can be made available.

Example measuring values for the symbol represented in diagram 2:

No.	Reg.	Class.	Name	Unit	Number	Ave.	Contrast[1]	Min[2]	Max[2]
0	0	Symbol	H	L-cd/m²	6069	2.06	0.61	1.57	2.58

[1] There are various contrast and uniformity criteria available: min/max, variance, variance/average, (max-min)/average, etc.

[2] The calculation of the minimum/maximum is performed using an adjustable circle diameter (in the example 10 pixels). The positions of these limit values within the symbol can be shown using the corresponding circles marked “<” and “>”.

Besides the luminance, also the tristimulus values (x,y according to CIE31) as well as the dominant wavelength, which can be derived from that, can be determined in a space-resolved way [3].

Contrast measurement on displays using hypercentric lenses

For data acquisition, luminances can be imaged onto different pixels of the matrix from various directions using a hypercentric lens (conoscopic lens). If the distance to the object is properly adjusted, all light bundles recorded come approximately from the same section of the display.

The contrast determination on displays can be performed by setting off two captures (display bright or also dark) taken by means of such a lens.

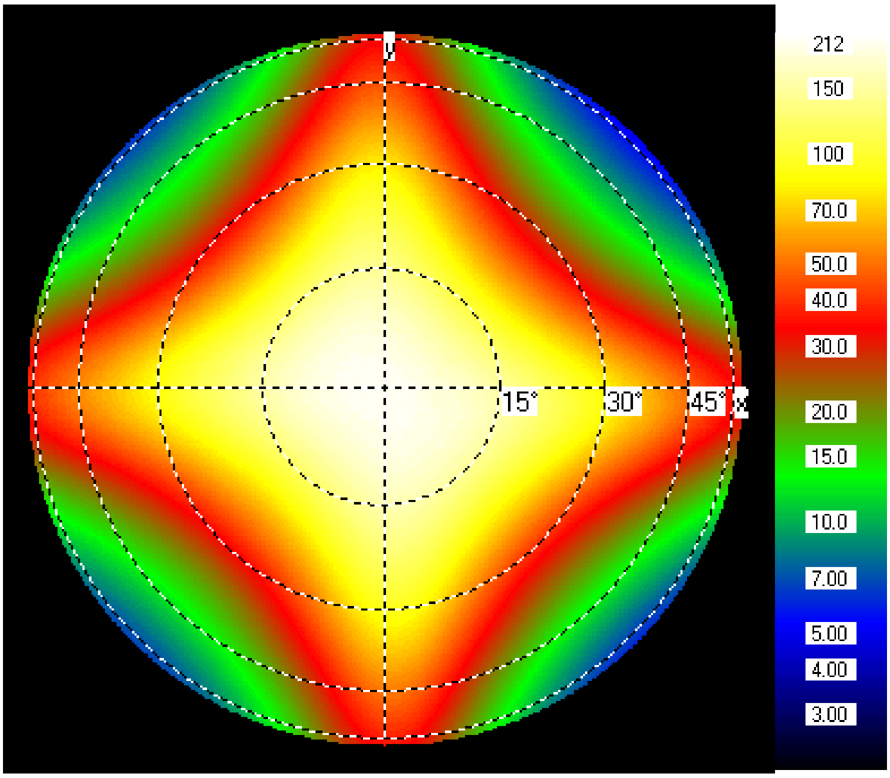


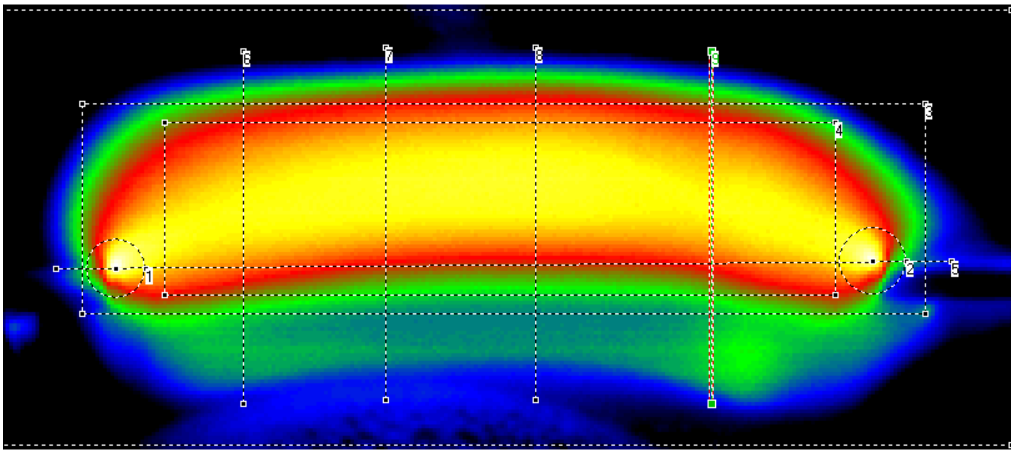
Diagram 3: Contrast k = L_{bright} / L_{dark} as a function f(φ,θ) in logarithmic pseudo color representation

Measurement of lamps

Lamps are, in general, small objects. For measuring them, imaging systems with an reproduction scale of $\beta' \approx 1$ are required. This is principally possible using macro lenses or lenses with great focal length. However, the heat development of the lamps must be taken into account. Therefore, a higher working distance should be guaranteed.

The high luminances require the use of neutral-density filters. In case of a high attenuation (small transmissions $\tau < 10^{-3}$), the spectral dependences $\tau(\lambda)$ are to be considered as the filters are no longer “grey”. If the spectral emission of the lamps is known, a CCF (color correction factor) can be calculated.

The luminances can be represented in various scalings, and the evaluation in certain regions (e.g. above lines) can be effected very quickly and from various points of views.



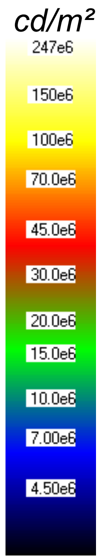


Diagram 4: Luminance image of the arc of a xenon lamp (logarithmic pseudocolor representation with object markings)

If a luminance measuring camera is mounted on a goniometer, it is possible to record luminance images from different directions around the measuring object (luminaire, lamp). Applying the method according to Prof. Riemann, these luminance images can be combined to one luminance distribution L (x,y,z,δ,φ) describing the measuring object completely [4].

From these data, luminous intensity distribution and luminous fluxes of lamps and luminaries can be determined. The measuring method applied permits the lamp and luminaire parameters to be determined in normal position and far within the photometric limit distance.

Goniophotometers of such kind no longer assume luminaries/ lamps to be point sources of light. Measuring data (ray data) can be determined which can be used particularly in the near field of luminaries/ lamps for the simulation and exact evaluation of lighting-engineering devices as well as for illumination planning.

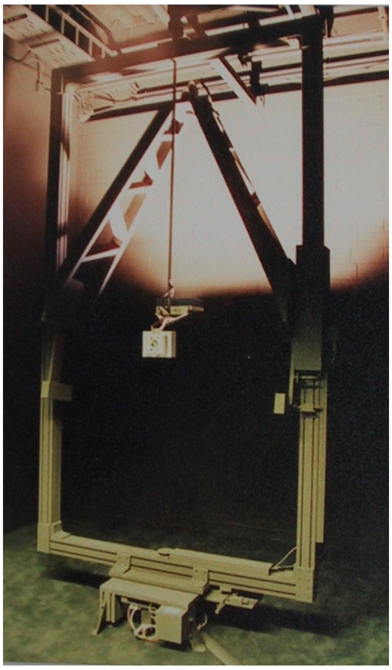


Diagram 5: Goniophotometer

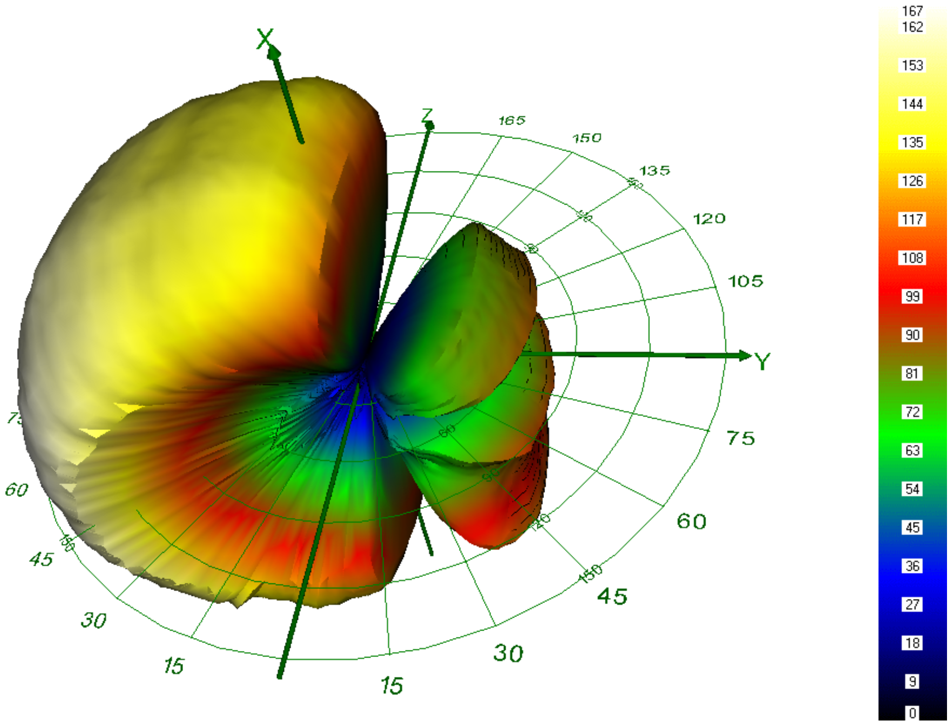


Diagram 6: 3D-representation of a luminous intensity distribution body type Philips D2R lamp 35W), scaling in cd/klm

Evaluation of road and tunnel illuminations

For evaluating road and tunnel illuminations, low luminances must be recorded, sometimes also out of vehicles in motion. The luminance data of any number of measuring points can be recorded. For this, it should be possible to save the arrangement of the measuring points separately in order to make sure that several images can be used for the evaluation. The data can be evaluated by means of luminance sectional views or the discrete measuring points according to DIN EN 13201-4. In addition, the evaluation of gradients and uniformity along a line from these values is also possible.

For analysing the image data, pseudocolor and the ISO color representation of surfaces can be very helpful. In comparison with the gray representation, the use of false pseudocolors allows a better visual analysis of the uniformity of the luminance distribution. By means of the ISO color representation, it is possible to represent single luminance areas separately in color (e.g. in case of special requirements set by standards).

Besides the perspective representation of the luminance distribution as an image, also the equalization of the image data may sometimes be necessary. The world coordinates being known, the luminance image can be converted into an orthogonal representation of the evaluation plane. By combining these image data, a common perspective and orthogonal representation can then be obtained (diagram 7).

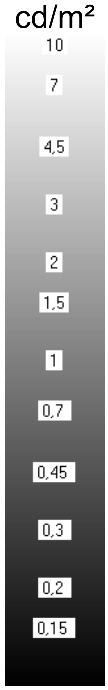


Diagram 7: Road scene with measuring points and appertaining orthogonal representation (logarithmic scaling of the measuring values)

References

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