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TECHNICAL REPORT

Characterization of Imaging Luminance Measurement Devices (ILMDs)

CIE 244:2021

UDC: 535.24
535.243

Descriptor: Photometry
Spectrophotometry

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3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
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5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

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This Technical Report has been prepared by CIE Technical Committee (TC) 2-59 of Division 2 "Physical Measurement of Light and Radiation" and has been approved by the Board of Administration and by Division 4 of the Commission Internationale de l'Eclairage. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory.

Ce rapport technique a été élaboré par le Comité Technique (TC) 2-59 de la CIE Division 2 "Mesures Physiques de la Lumière et des Radiations" et a été approuvé par le Bureau et Division 4 de la Commission Internationale de l'Eclairage. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire.

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CONTENTS

Summary	vi
Résumé	vi
Zusammenfassung	vi
1 Scope	1
2 Terms and definitions	2
2.1 Terms related to devices	2
2.2 Terms related to photometry	5
2.3 Quality indices	7
3 Extended descriptions for some definitions	11
3.1 Image sensor	11
3.2 Objective	11
3.3 ILMD types	12
3.4 Coordinate systems	12
3.4.1 Camera coordinate system	13
3.4.2 Image coordinate system	13
3.4.3 Device coordinate system	15
3.4.4 Object coordinate system	16
3.4.5 Element coordinate system	16
3.5 Acceptance areas and measurement field	16
3.6 Evaluation region	17
3.6.1 Definition using a label image	17
3.6.2 Geometrical definition	17
3.6.3 Photometric definition	17
4 Measurement values	18
4.1 General	18
4.2 Luminance (in a given direction, at a given point of a real or imaginary surface)....	18
4.2.1 Average luminance	19
4.2.2 Luminance distribution	20
4.2.3 Projection of a luminance distribution	20
5 Methods for the adjustment and calibration	21
5.1 General	21
5.2 Adjustment	22
5.3 Initial adjustment index	23
5.4 Calibration methods	23
5.5 Calibration using a single evaluation region	24
6 Properties of ILMDs	26
6.1 General considerations	26
6.2 Special consideration for ILMDs	27
6.3 Spectral properties	29
6.3.1 General	29
6.3.2 General $V(\lambda)$ mismatch index, f'_1	29
6.4 UV response	31
6.5 IR response	31
6.6 Linearity	31
6.6.1 General	31

6.6.2	Detection limit	32
6.6.3	Linearity Measurement	32
6.7	Range change	33
6.8	Focusing distance	33
6.9	Temperature.....	33
6.10	Modulated light.....	33
6.11	Polarization dependence	33
6.12	ILMD related quality indices	34
6.12.1	Introduction	34
6.12.2	General uniformity	34
6.12.3	Effect of surrounding field.....	36
6.12.4	Stray light influence for negative contrast	38
6.12.5	Edge function	39
6.12.6	Influence of smear	41
6.12.7	Shutter repeatability	42
6.12.8	Aperture repeatability	43
6.12.9	Size-of-source effect	43
7	Recommendations	44
7.1	Recommendations for the user	44
7.2	Recommendations for the manufacturer	45
7.2.1	General considerations	45
7.2.2	Measurement protocol	46
7.2.3	Design considerations	46
Annex A	Measurement uncertainties	47
A.1	Uncertainty contribution images	47
A.1.1.	Notation.....	47
A.1.2.	Model and uncertainty contribution	48
Annex B	The effect of the entrance pupil	50
Annex C	Remarks on average luminance	52
References		53

CHARACTERIZATION OF IMAGING LUMINANCE MEASUREMENT DEVICES

Summary

This technical report describes the elements, function and characterization of imaging luminance measuring devices (ILMDs). Furthermore, the calibration of ILMDs is described and some guidelines for their use are provided.

Using ILMDs the projection of the luminance distribution of a scene can be recorded and made available for further evaluation. In addition to a simple documentation of measurements, the geometrical assignment of the image points into the object coordinate system often allows more complex calculations by combining luminance, directional and, if necessary, solid angle information (e.g. for glare evaluation). In addition to the flexible evaluation option, it is possible to acquire a large number of measured values quickly and, if necessary, even synchronously. Furthermore, the type of evaluation can also be coupled to the image content, i.e. the image areas to be evaluated can be determined in the image either by their position within the image or by their luminance value.

CARACTÉRISATION DES INSTRUMENTS DE MESURE DE LUMINANCE À RÉOLUTION SPATIALE

Résumé

Le rapport technique suivant décrit les éléments, le mode de fonctionnement et la caractérisation des caméras pour la mesure de la luminance (imaging luminance measuring devices – ILMD). En outre, l'étalonnage des ILMD est décrit et des conseils d'utilisation des systèmes sont donnés.

En utilisant les ILMD, la projection de la distribution de la luminance d'une scène peut être enregistrée et mise à disposition pour une évaluation plus approfondie. En plus d'une simple documentation des mesures, l'affectation géométrique des points d'image dans le système de coordonnées de l'objet permet souvent des calculs plus complexes en combinant les informations de luminance, de direction et, si nécessaire, d'angle solide (par exemple pour l'évaluation de l'éblouissement). Au-delà de la flexibilité de l'évaluation, il est possible d'acquérir rapidement un grand nombre de valeurs mesurées et, si nécessaire, même de manière synchrone. En outre, le type d'évaluation peut également être couplé au contenu de l'image, c'est-à-dire que les zones d'image à évaluer peuvent être déterminées dans l'image ou par leur position dans l'image ou par leur valeur de luminance.

CHARAKTERISIERUNG ORTSAUFLÖSENDER LEUCHTDICHTEMESSKAMERAS

Zusammenfassung

Der vorliegende Technische Report beschreibt den Aufbau, die Wirkungsweise und die Charakterisierung von Leuchtdichtemesskameras. Weiterhin wird die Kalibrierung von Leuchtdichtemesskameras beschrieben, und es werden Hinweise für ihren Einsatz gegeben.

Mit Hilfe von Leuchtdichtemesskameras wird die Projektion der Leuchtdichteverteilung einer Szene erfasst und für weitere Auswertungen zur Verfügung gestellt. Durch die geometrische Zuordnung der Bildpunkte in das Objektkoordinatensystem können neben einer einfachen Dokumentation von Messungen oft auch komplexere Berechnungen durch die Zusammenfassung von Leuchtdichte-, Richtungs- und ggf. Raumwinkelinformation durchgeführt werden, wie dies z.B. bei der Blendungsbewertung notwendig ist. Neben der flexiblen Auswertemöglichkeit ist die schnelle und ggf. sogar synchrone Erfassung einer Vielzahl von Messwerten möglich. Weiterhin kann die Art der Auswertung auch an den Bildinhalt gekoppelt werden, d.h. es können die auszuwertenden Bildbereiche im Bild entweder über Ihre Lage im Bild oder über die Leuchtdichte bestimmt werden.

1 Scope

The basic task of imaging luminance measurement devices (ILMDs) is to measure (the projection of) the *spatial luminance distribution* of (self-radiating) extended sources and illuminated surfaces. In literature, different terms may be found to describe the same device such as: multi-channel luminance meter, luminance mapper, array (or matrix) luminance meter, video photometer, CCD luminance meter, luminance camera or spatial luminance profile device.

Compared with a traditional spot luminance measurement device (LMD) the user of an ILMD measures a luminance image containing not only *one* spatially averaged luminance measurement value of the object for one direction. An ILMD samples an object by many measurement points. In addition, information about the surrounding of the object is obtained. It is therefore possible to evaluate a luminance image in different ways, e.g. using different regions and illustrating these regions directly on a displayed image. An example is given in Figures 1-3.

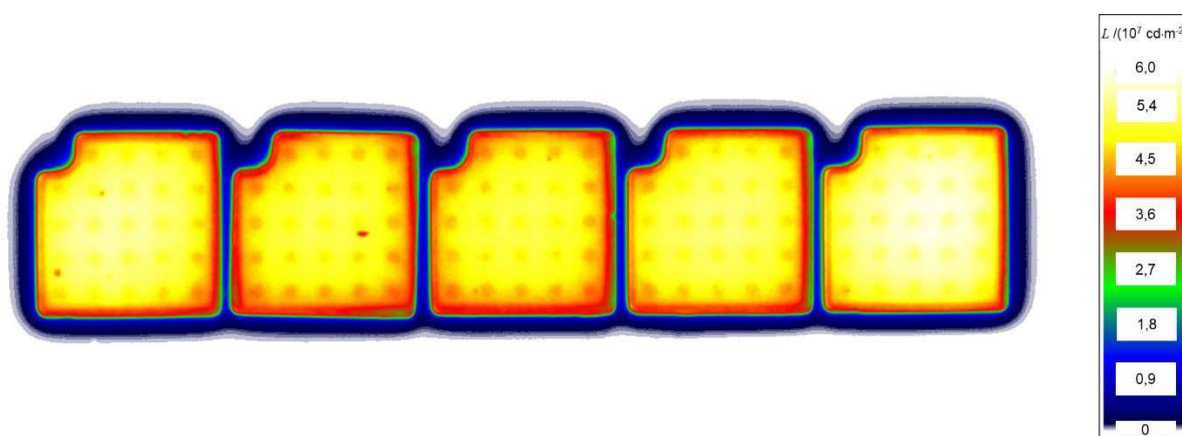


Figure 1 – Luminance image (LED assembly) (linear scale)

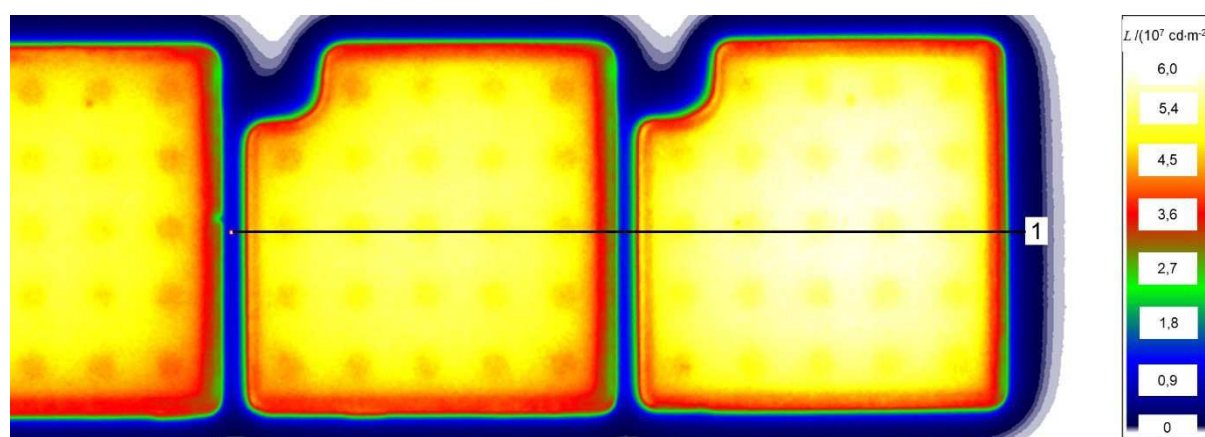


Figure 2 – Luminance image (LED assembly) (detail, enlarged, linear scale), with indication of line ("1") for sectional view of luminance distribution according to Figure 3

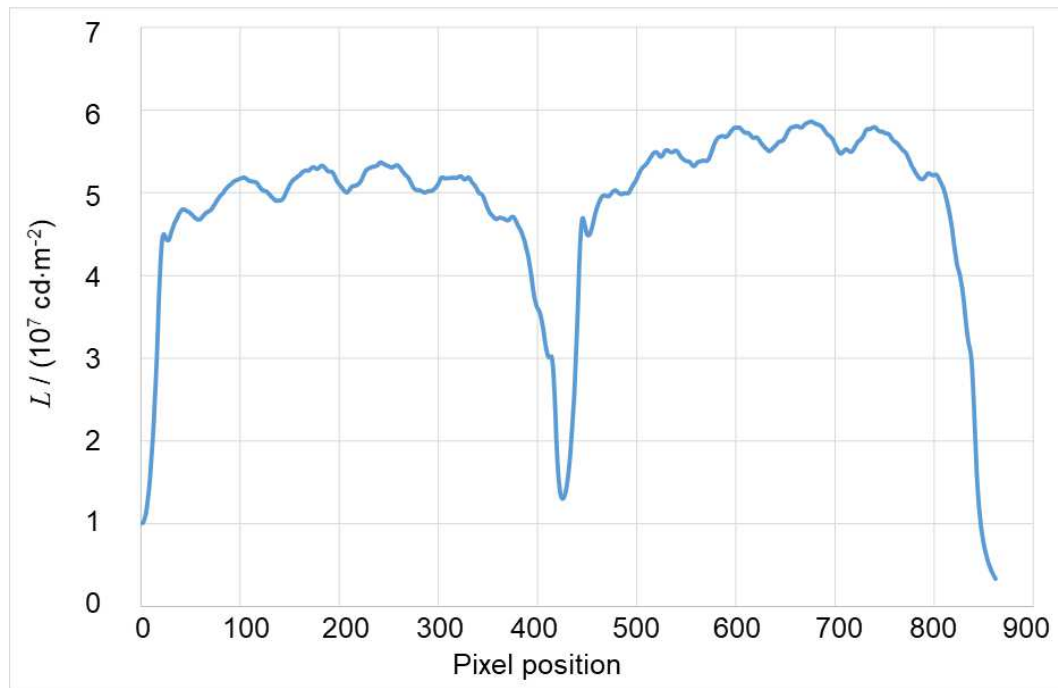


Figure 3 – Evaluation example: Sectional view of luminance distribution along the line (indicated by "1") in Figure 2

Due to their properties, ILMDs are used for a wide range of applications including the characterization of displays, near-field goniophotometry, or visibility and lighting studies of complex scenes. Their advantages are clearly:

- temporal synchronized measurement of a large number of measurement points;
- direct spatial identification of the measurement object (documentation);
- arbitrary geometrical shape of multiple measurement fields and complex evaluations (e.g. luminance-based evaluation shapes).

The objective of this document is to

- give clear definitions for the individual characteristics which can be used for evaluating the performance of ILMDs;
- recommend methods for the characterization and the calibration of these devices;
- provide a guideline for the selection and correct use of these measurement devices.

2 Terms and definitions

For the purpose of this document the definitions given in the International Lighting Vocabulary (ILV) (CIE, 2020) and the following definitions, symbols and abbreviations apply.

2.1 Terms related to devices

2.1.1

image sensor

an optoelectronic device which produces electrical signals representing the optical characteristics of an image

[SOURCE: IEC 60050-723 / Electropedia, entry 723-07-05]

Note 1 to entry: See 3.1 for an extended description.

2.1.2**objective**

first part of the imaging system, consisting of a lens, its mount and any associated parts, which forms a primary image of the object, either alone or in conjunction with a tube lens

[SOURCE: ISO 10934:2020]

Note 1 to entry See 3.2 for an extended description.

2.1.3 **$V(\lambda)$ -correction filter**

full filter designed in such a way that the relative spectral responsivity of the complete system matches the spectral luminous efficiency function for photopic vision, $V(\lambda)$

Note 1 to entry: If the image sensor is using a colour filter on chip (single-chip colour sensors), the $V(\lambda)$ -correction filter has to be designed in connection with the (matrix) conversion of the sensor readout to match the spectral luminous efficiency function for photopic vision, $V(\lambda)$, as defined in (ISO/CIE, 2005). With the matrix conversion the values of the single channels (e.g. R, G and B for a colour sensor) will be converted to one output channel. Systems with more than one full filter or other methods to change the spectral responsivity of the system should be used in a similar way.

Note 2 to entry: The spectral responsivity of the system must be measured over the complete spectral responsivity range of the sensor (e.g. 350 nm to 1 100 nm for standard CCD sensors).

2.1.4**imaging luminance measurement device****ILMD**

instrument for measuring the projection of a portion of the spatial and angular resolved luminance distribution in a certain main direction comprising a detector array, a $V(\lambda)$ -correction filter, an objective, electronic components, firmware and display unit

Note 1 to entry: The detector array can be e.g. a CCD array, a CMOS array, etc. The electronic components can include e.g. an analogue-digital converter, sample and hold circuit, etc.

Note 2 to entry: In the literature different terms can be found to describe the same device such as imaging photometer, multi-channel luminance meter, luminance mapper, array (or matrix) luminance meter, video photometer, CCD luminance meter, luminance camera or spatial luminance profile device.

2.1.5**ILMD type I**

ILMD with luminance calibration only where each pixel, (i, j) , in the luminance image, L , holds the luminance information as seen in the scene

Note 1 to entry: Geometric information is neither necessary nor required for image evaluation.

2.1.6**ILMD type II**

ILMD with luminance and geometrical calibration where each pixel, (i, j) , in the luminance image, L , stands for a luminance value in the scene and the associated information about the direction $(\vartheta_C(i, j), \varphi_C(i, j))$, position $(x_S(i, j), y_S(i, j))$ and the seen solid angle $\Delta\Omega_{\text{Pixel}}(i, j)$

Note 1 to entry: For this type of ILMD a photometric and geometric calibration is necessary.

2.1.7**digital camera**

optoelectronic device comprising an objective, an image sensor (i.e. CCD, CMOS,...) and electronic components

Note 1 to entry: The electronic components can include e.g. an analogue-digital converter, sample and hold circuits, etc.

Note 2 to entry: In this document digital cameras will be assumed, delivering the image data generated from the image sensor in a digital form. These data will be called "raw data".

Note 3 to entry: In this document the term "camera" is used with the meaning of "digital camera".

2.1.8

RAW image

image of a camera or imaging luminance measurement device which is captured during the exposure process without any corrections by algorithms

2.1.9

sensor pixel

smallest geometrically resolvable area of a two-dimensional area sensor of a camera or imaging luminance measurement device

Note 1 to entry: A sensor pixel, represented by an area ($\Delta x \cdot \Delta y$), contains the sensitive area (active area) as well as the non-sensitive areas between the active areas (passive area).

Note 2 to entry: Sometimes not all pixels of a sensor are read out (partial area scan for CCD sensors or random access for CMOS sensors).

Note 3 to entry: In this document the term "pixel" is used for an element of the evaluation image if the difference between macro pixel and sensor pixel is not relevant.

2.1.10

image resolution

number of pixels, expressed by number of columns by number of rows, or total number of pixels, typically indicated in megapixels

Note 1 to entry: The number of stated horizontal and vertical pixels as well as the total number of pixels should include only original elementary pixels having a physical representation and can be read out separately (not interpolation or other enhancement algorithms in use).

2.1.11

macro pixel

collection of neighbouring pixels which are grouped together either during the image capture at the sensor (analogue binning) or during the image processing (digital binning)

Note 1 to entry: In this document the term "pixel" is used for an element of the evaluation image if the difference between macro pixel and sensor pixel is not relevant.

Note 2 to entry: The use of macro pixels can change the maximal usable saturation of a sensor and can influence the statistical parameters of the pixel signal, and therefore must be taken into account for the measurement uncertainty evaluation.

Note 3 to entry: A macro pixel is also generated if a number of pixels of the evaluation image is grouped before the evaluation. This also influences the statistical parameters of the evaluated data. (See "virtual spot area scan" for the evaluation of the system uniformity in 6.12.2.1)

2.1.12

binning

summing up the charge or digital signal of neighbouring pixels into one macro pixel

Note 1 to entry: Binning leads to a reduction of the image resolution of the result image, but conversely to an increase of the responsivity of the system.

Note 2 to entry: A combination of analogue and digital binning is possible.

2.1.13

analogue binning

summing up the charge of pixels inside the sensor before the charge-voltage conversion

2.1.14

digital binning

summing up the signal of pixels during the digital signal processing carried out by the camera or firmware

2.1.15

integration time

time interval during which the radiation incident on a sensor is converted into an output signal

Note 1 to entry: The output signal can be a charge, current, voltage, etc.

Note 2 to entry: For integrating sensors (e.g. CCD) that are not saturated, the output signal has a nearly linear dependence on the integration time.

Note 3 to entry: For ILMDs which use mechanical shutters for the exposure control, there is a formal difference between exposure time (interval over which the radiation hits the sensor) and integration time (interval over which the charge is accumulated). It is normally assumed that this difference is negligible and therefore the exposure time is equal to the integration time.

2.1.16

firmware

data sets and software applied in the camera system or in the connected evaluation system (computer) to convert the raw data from the camera into luminance images

Note 1 to entry: The firmware controls the capture of the RAW images, the readout of the images and their conversion into luminance images.

2.2 Terms related to photometry

2.2.1

luminance

L_v ; L

density of luminous intensity with respect to projected area in a specified direction at a specified point on a real or imaginary surface, expressed by

$$L_v = \frac{dI_v}{dA \cos \alpha}$$

where I_v is luminous intensity, A is area and α is the angle between the normal to the surface at the specified point and the given direction

Note 6 to entry: The equation in the definition can also be described as a function of luminous flux, Φ_v . In this case, it is mathematically interpreted as a second partial derivative of the luminous flux at a specified point (x, y) in space in a specified direction (ϑ, φ) with respect to projected area, $A \cdot \cos \alpha$, and solid angle, Ω ,

$$L_v(x, y, \vartheta, \varphi) = \frac{\partial^2 \Phi_v(x, y, \vartheta, \varphi)}{\partial A(x, y) \cdot \cos \alpha \cdot \partial \Omega(\vartheta, \varphi)}$$

where α is the angle between the normal to that area at the specified point and the specified direction.

[SOURCE: CIE S 017:2020, entry 17-21-050, Notes 1 to 5 and 7 to 10 to entry omitted]

2.2.2

luminance distribution

distribution of the luminance on a surface as a function of the position on the surface and the viewing direction

Note 1 to entry: The luminance distribution is a five-dimensional quantity: its amplitude depends on the position of the surface element and the direction. The coordinates of the surface elements are given in object coordinates while the direction is given in element coordinates.

2.2.3

projection of a luminance distribution

mapping of the luminance distribution, $L(x_S, y_S, z_S, \vartheta_E, \varphi_E)$, of a (real or imaginary) luminous surface onto the image plane through the centre of the projection

Note 1 to entry: The projection from the point (x_S, y_S, z_S) onto the image plane is the intersection of the line starting from (x_S, y_S, z_S) through the centre of the projection and the image plane (see 3.4.1 for details).

Note 2 to entry: This projection is called central projection.

Note 3 to entry: Using an ILMD the projection is focused onto the image plane of the ILMD. The result is the luminance image, L .

2.2.4

luminance image

L

digital description of the projection of a luminance distribution onto an image plane with a plane normal to the projection direction

Note1 to entry: Without additional knowledge about the specific observed surface of the measurement object only the direction of the projection can be determined from the luminance image.

Note2 to entry: A luminance image is a set of luminance values, $L(i, j)$, of an image sensor with $(N \times M)$ sensor elements (pixels) in the ILMD.

2.2.5

entrance pupil

EP

image of the aperture stop in the object space

Note 1 to entry: If the aperture stop is the first component encountered by the radiation, the entrance pupil is in coincidence with the aperture stop.

[SOURCE: ISO 9334:2012, 4.8]

2.2.6

acceptance area

area in a scene emitting radiation which is transferred by the objective into the ILMD

Note 1 to entry: The acceptance area is usually larger than the measurement field of the sensor as it includes indirect (stray) light from the surrounding field.

Note 2 to entry: See 3.5 for an extended description of the difference between measurement field and acceptance area.

2.2.7

measurement field, <for ILMD measurements>

sum total of all area elements in the object space, radiating towards the entrance pupil of the lens, collected by sensitive pixels of the detector area

Note 1 to entry: For the objective of the ILMD it is recommended to indicate the measurement distance and the measurement field for fixed focus objectives and the minimum (and maximum if possible) measurement distance and measurement field for focusable objectives.

Note 2 to entry: The measurement field is, in general, roughly rectangular. It can, however, have other shapes (e.g. circular shape for hemispherical or conoscopic objectives).

Note 3 to entry: A measurement field without any specification, clarification or additional description is the measurement field of the complete detector area (all sensitive pixels). For other measurement fields an additional description is needed.

2.2.8

measurement field angle

angle spanned by the distant measurement field to the centre of projection

Note 1 to entry: The measurement field angle is given for the horizontal and vertical part of the image or for the diagonal of the image and is given as the angle between the optical axis and the main ray of the corresponding image border point.

Note 2 to entry: As an alternative to the measurement field angle, the seen object solid angle can be given for a system. This solid angle is called "measurement field solid angle".

Note 3 to entry: The measurement field angle is expressed in radian (rad) or degree (°).

2.2.9

evaluation region

set of area elements (pixels in the image plane) summarized to one result

Note 1 to entry: The purpose of an evaluation region is usually to calculate the mean value and other statistical parameters.

Note 2 to entry: It is common to use linear, rectangular, circular, elliptical and polygonal regions or a logical combination of these regions.

Note 3 to entry: The set of points can be defined by the pixel values (e.g. all pixels above a certain luminance threshold).

Note 4 to entry: It is possible to use irregular sets of pixels.

Note 5 to entry: It is not necessary that the set of pixels of the evaluation region is contiguous.

Note 6 to entry: See 3.6 for further explanation.

2.2.10

label image

B

digital image with the size of the evaluation region or the whole luminance image generated to classify the properties of a pixel in the luminance image

Note 1 to entry: The label image is the result of a pixel classification based on selected rules and will be used to make statistical evaluations. See 3.6.1 for a detailed description and use.

2.2.11

measurement field, <of a pixel>

set of points in the object space, illuminating the entrance pupil and registered by the pixel with a directionally dependent responsivity of at least 10 % of the maximal responsivity of that pixel

2.2.12

measurement field, <of an evaluation region>

set of all points in the object space, illuminating the entrance pupil and registered by all pixels of the evaluation region with a directionally dependent responsivity of at least 10 % of the maximal responsivity of that evaluation region

Note 1 to entry: Using ILMDs it is possible to define and use more than one evaluation region at the same time, and these regions may be differently shaped, may be contiguous and may be overlapping.

2.3 Quality indices

The properties of “classical” luminance meters are described in ISO/CIE 19476:2014 “Characterization of the Performance of Illuminance Meters and Luminance Meters” (ISO/CIE, 2014). The present report applies, whenever possible, a similar terminology for ILMDs. In addition, some practical aspects for the characterization of ILMDs are given. Compared to “classical” luminance meters, ILMDs present some further properties to be taken into account:

- The measurement and evaluation are typically carried out by software. The transformation from the physical signal (collected photons) into the indicated luminance values may be complex, and sometimes image processing and image compression algorithms are used, e.g. to reduce the data size;
- ILMDs have a large number of individual detectors called pixels. Considering the system as individual detectors would mean that each detector has its own characteristics. However, in practice these pixels are combined (by hardware or mathematically) to form measurement regions (evaluation regions);
- Some of the commercially available ILMDs allow easy exchange of the optical system (change of focal length, focus, apertures, objectives and neutral density filters). In general, the parameters for characterizing ILMDs are only valid for a very specific configuration (specified focal length, specified focus, specified apertures, etc.), to be stated together with the quality indices;

NOTE 1 In (ISO/CIE, 2014) illuminance meters and luminance meters are sometimes collectively referred to as “photometers”. In this document those definitions taken directly from ISO/CIE 19476:2014 referring to photometers are understood as referring to ILMDs.

NOTE 2 This subclause is just introducing the quality indices and stating their source where necessary. More information about the quality indices and how they are determined is given in Clause 6.

A set of quality indices is used to characterize the performance of photometers. Quality indices are physical quantities characterizing selected properties of a photometer. They are normalized response values, which do not describe errors directly and thus cannot be used for correction.

The name for each index has been taken from the physical effect influencing its value to make it easier to memorize and understand its meaning.

A quality index is symbolized by the character " f_x " where the subscript "x" specifies the considered property. The values of quality indices are:

- evaluated by formulae specific for each property, from data determined under specified measurement conditions;
- stated as a percentage, with associated uncertainties; and
- ideally zero.

The quality indices of photometers alone do not allow the estimation of the measurement uncertainty for a specific measurement task. Nevertheless, it is generally true that instruments with smaller f_x values, in most cases, achieve smaller measurement uncertainties than instruments with larger values.

2.3.1 initial adjustment index

f_{adj}

index describing the absolute value of the relative deviation of the photometer indication from the corresponding reference value

[SOURCE: ISO/CIE 19476:2014, 3.2.1 – modified: "absolute relative deviation" replaced with "absolute value of the relative deviation"]

Note 1 to entry: For ILMDs the initial adjustment should be done using a single point calibration similar to the use of "classical" luminance meters.

2.3.2 general $V(\lambda)$ mismatch index

f_1'

index describing the deviation of the relative spectral responsivity of the photometer from the $V(\lambda)$ function

[SOURCE: ISO/CIE 19476:2014, 3.2.2]

2.3.3 UV response index

f_{UV}

index describing the responsivity of the photometer to UV radiation

[SOURCE: ISO/CIE 19476:2014, 3.2.3]

2.3.4 IR response index

f_{IR}

index describing the responsivity of the photometer to IR radiation

[SOURCE: ISO/CIE 19476:2014, 3.2.4]

2.3.5 detection limit index

$f_{3,0}$

index describing the smallest measurement value, which states a signal different from zero

Note 1 to entry: The detection limit can be caused by noise or limitations in the digital readout or analogue-to-digital conversion.

2.3.6**linearity index**, <of an ILMD, fixed measurement range> $f_{3,1}$

index describing the deviation from linearity of the ILMD response with respect to the luminance measured at different levels without changing the measurement range of the ILMD

Note 1 to entry: The change of the measurement range of the ILMD can be the change of the integration time, gain, aperture or neutral density filter used.

2.3.7**linearity index**, <of an ILMD, using range change> $f_{3,2}$

index describing the deviation from linearity of the ILMD response at one luminance level while changing the load of the analogue-to-digital converter

Note 1 to entry: The load of the analogue-to-digital converter can be changed by varying the integration time, the gain, the aperture or the used neutral density filter.

2.3.8**temperature dependence index** $f_{6,T}$

index describing the influence of ambient temperature on the photometer responsivity when the ambient temperature differs from that at the time of calibration

[SOURCE: ISO/CIE 19476:2014, 3.2.16]

2.3.9**modulated light index** f_7

index describing the influence of modulated light at various frequencies, compared to the response for a constant luminance condition

[SOURCE: ISO/CIE 19476:2014, 3.2.18]

2.3.10**polarization response index** f_8

index describing the influence of polarized light on the responsivity of the photometer

[SOURCE: ISO/CIE 19476:2014, 3.2.19]

2.3.11**range change index** f_{11}

index describing the influence of range settings of display-units or amplifiers

[SOURCE: ISO/CIE 19476:2014, 3.2.21]

Note 1 to entry: For an ILMD this can be done by changing the gain, binning, aperture or other settings that change the responsivity of the system.

2.3.12**focusing distance index** f_{12}

index describing the influence of deviations of the test distance from the focus distance for luminance meters

[SOURCE: ISO/CIE 19476:2014, 3.2.22]

2.3.13

responsivity uniformity for flat field index

f_{21}

index describing the spatial and directional uniformity of the responsivity of an ILMD for measurements of large areas that cover the entire measurement field (flat field)

2.3.14

responsivity uniformity for spots index

f_{22}

index describing the spatial and directional uniformity of the responsivity of an ILMD for measurements of small luminous areas (spots) with respect to the measurement field

2.3.15

effect of surrounding field index

f_{23}

index describing the influence of the ambient luminance outside the measuring field of a luminance meter, which results from scattered light inside an ILMD

2.3.16

stray light influence for negative contrast index

f_{24}

index describing the influence of the scattered light originating from the measuring field for measurements of dark areas surrounded by bright areas

Note 1 to entry: The measurement of a luminance in a dark area surrounded by a bright area results in a negative contrast.

2.3.17

edge function index

f_{25}

index describing luminance measurements at luminance step functions

Note 1 to entry: A luminance step describes an abrupt change in luminance from high luminance to low luminance, called edge.

2.3.18

influence of smear index

f_{26}

index describing the influence of smear

2.3.19

shutter repeatability index

f_{27}

index describing the repeatability of the integration time realization of the shutter system

Note 1 to entry: The shutter repeatability can be measured for both electronic and mechanical shutter systems.

2.3.20

aperture repeatability index

f_{28}

index describing the repeatability of the aperture setting

Note 1 to entry: The repeatability is caused by the aperture setting for every image capture used for electronically controlled objectives and the aperture size dependence caused by the objective orientation with respect to gravity.

Note 2 to entry: For manual lenses the repeatability is usually only caused by the aperture size dependence caused by the objective orientation with respect to gravity.

2.3.21

size-of-source effect index

 f_{29}

index describing the size-of-source effect of the measurement system, which is related to scattered light inside an ILMD

3 Extended descriptions for some definitions

This clause contains extended descriptions for some terms defined in Clause 2.

3.1 Image sensor

There are different types of image sensors. In this document CCD and CMOS sensors are taken into account only.

CCD (charge-coupled device) (IEC 60050-521 / Electropedia, entry 521-11-16)

Charge-transfer device that stores electric charge in potential wells and transfers this electric charge almost completely as a packet by moving the potential wells.

- Full Frame: Using the complete sensor area for charge storage and charge transfer. A mechanic shutter performs exposure/integration control.
- Interline Transfer: The sensor area consists of the sensitive pixels and transportation registers. Exposure/Integration control is performed using an electronic shutter.

CMOS (complementary metal-oxide semiconductor)

Image Sensor based on a standard semiconductor technology.

- Linear with respect to the exposure
 - Global Shutter: Integration time control similar to interline transfer CCD sensors. All pixels start and stop the exposure at the same time.
 - Rolling Shutter: Start and stop of the integration line by line or area by area. The starting point of the exposure time is different depending on the pixel position.
- Non-Linear with respect to the exposure
 - Without integration time control. Pixels are accessed randomly and the photo current is measured at the time of the access.
 - Pixels have non-linear or piecewise linear transfer functions to increase the dynamic range of the pixel.

3.2 Objective

The explanation of the different objective types used to image a scene onto the sensor is not the focus of this document. See e.g. (Gross, 2011) for details and further explanations.

Types of objectives:

- Standard objective (entocentric)
- Telecentric objective
 - Image-space telecentric objective (rays collimated in the image space)
 - Object-space telecentric objective (rays collimated in the object space)
 - Bi-Telecentric objective (rays collimated in image and object space)
- Macro objective
- Microscopic objective
- Fisheye objective (wide-angle objective with extremely wide, hemispherical image)
- Conoscopic objective