Mesopic illuminance meter based on CCD fibre-optics spectroradiometer

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Abstract

Mesopic photometry is nowadays hot topic in the field of lighting engineering. It is mainly focused on exterior lighting system e.g. roadlighting, public lighting etc. where using of photometric system for mesopic photometry based on visual performance is reasonable due to level of luminances on the illuminated surface. Also assumption of mesopic photometry approach in such situations promotes using of luminaires with installed so-called rich-blue light sources with regard to Purkinje effect in visual process by human eye i.e. dynamic change of human sensitivity with maximum shift towards blue region. Practical implementation of CIE recommended system according to document CIE 191:2010 of photometric quantities is still waiting from research work for determination of adaptation luminance what some institutions and universities solve in their research work. The paper deals with construction of illuminance meter based on CCD fibre-optics spectroradiometer to measure illuminance level in the practice. Moreover using of this type of spectroradiometer is shown in some particular situations for outdoor lighting situations by assuming existing models about determination of the adaptation luminance.

Keywords: Mesopic photometry, Illuminance meter, CCD Spectroradiometers

Introduction

At the present the mesopic photometry is hot topic in lighting engineering especially in the public lighting. The mesopic photometry is used in particular to consider roadlighting photometric parameters where mesopic vison is relevant to car drivers and pedestrians.At the present the investigation about assessment of the adaptation luminance, visual field is undergoing in the frame of work joined technical committee JTC-001 in CIE. Furthermore measurement in the mesopic region is also limited to this requirement. Some models of assessment of visual field for determination of adaptation luminance exist at the present. However the validation process it still needed to use these models in the practice. Instruments used for measurement in the mesopic photometry have to follow model from recommendation. Therefore using of spectroradiometers in this range is valueable because besides knowing value of photometric quantity can be measured also spectral power distribution of measured light what can be used for other processing e.g. colorimetric information etc. Even more using of spectroradiometers for the measurement avoiding spectral mismatch error what the measurement with filter devices shall be assumed. CCD spectroradiometers provide full spectrum information in the range of interest in real time and for all wavelengths without needing to measure spectrum wavelength by wavelength scanning what is needed in the measurement by traditional desktop spectroradiometers. In the outdoor applications the illuminance level is important for some cases to verify lighting calculations mostly performed at the present by software tools. It should provide practical solutions in the mesopic photometry. One of this topic is devoted to roadlighting calculations. Methodology of roadlighting calculations is laid down in the document CIE 140:2000 which is currently under revision at CIE Division 4

(TC 4-15). Calculations are still based on photopic vision, i. e. photopic photometric quantities what disqualifies some innovative light sources mounted into luminaires which could be more efficient than traditional light sources if taking into account the mesopic conditions. It means that the old approach suppresses the usage of these luminaires because it does not consider appropriately the processes in the mesopic region where efficiency of the human eye is different. It depends on particular situation on the road and it is influenced by many other parameters. Therefore, new approach in the roadlight calculation emerged as a necessity for lighting engineers, who deal with roadlight, to consider mesopic conditions. Some preliminary results have been published in papers dealing with calculations based on the S/P ratio.

Mesopic photometry

The mesopic photometry is historically very well known from the beginning of previous century. Although the physiological processes in the human eye are very-well known the real application of the mesopic photometry into the practice is still not possible due to different reasons. Many years scientists over the world were trying to found connections between vision in the mesopic photometry and photometric quantities. Especially they wanted to establish clear relation between brightness of the object or scene as qualitative aspect of the vision of observer and quantitative expression by means of luminance. These attempts were not every time successful because response of rods and cones in the mesopic region work in different way and they were not allowed establish this relation in clear way. Even more additivity law what is working in good way in photopic and scotopic region was not possible to use for expression of photometric quantities. At the beginning of 90's of 20th century started slightly appear another approach how to describe mesopic vision with system which should follow additivity law through vision performance. Therefore in 2010 was at the CIE level accepted unified recommended system for mesopic photometry completed by release of CIE document 191:2010 Recommended System for Photometry Based on Visual Performance [1] based on visual performance of observer. This system allow to use additivity law what is the one of main requirement for this system and also allow to express human eye responsivity function $V_{mes}(\lambda)$ in the mesopic region. This function is not unique over the whole region of mesopic photometry i.e. between luminance levels 0,005 cd.m^{-2} and 5 cd.m^{-2} because that function is dynamically changing due to different contribution of rods and cones to the vision at different luminance level in respect with adaptation luminance. This combination of rods and cones is described in the present system by linear combination of functions $V(\lambda)$ and $V'(\lambda)$ weighted by parameter m which express the measure of contribution either rods or cones to the visual perception and has a value between 0 and 1.

$$M(m).V_{\mathrm{mes}}(\lambda) = m.V(\lambda) + (1-m)V'(\lambda) \qquad \text{for } 0 \le m \le 1$$

and

(1)

$$L_{\mathrm{mes}} = \frac{683}{V(\lambda_0)}.\int L_{\mathrm{e}}(\lambda).V_{\mathrm{mes}}(\lambda)\mathrm{d}\lambda$$

where

$M(m)$	is normalising function such that $V_{\mathrm{mes}}(\lambda)$ attains a maximum value of 1
L_{mes}	is mesopic luminance
$V_{\mathrm{mes}}(\lambda_0)$	is the value of $V_{\mathrm{mes}}(\lambda)$ at the 555 nm
$L_{\mathrm{e}}(\lambda)$	is the spectral radiance in W.m^{-2}.sr^{-1}.nm^{-1}

If L_{mes} ≤ 0,005 cd.m^{-2} then m=0 and if L_{mes} ≥ 5 cd.m^{-2} then m=1. The coefficient m and the mesopic luminance L_{mes} can be calculated using iterative approach as follows

$$m_0 = 0{,}5$$

$$L_{mes,n} = \frac{m_{(n-1)} L_p + (1 - m_{(n-1)}) L_s V'(\lambda_0)}{m_{(n-1)} + (1 - m_{(n-1)}) V'(\lambda_0)} \qquad (2)$$

$$m_n = a + b \log_{10}(L_{mes,n}) \qquad for \quad 0 \le m \le 1$$

where

L_p	is the photopic luminance
L_s	is the scotopic luminance
$V'(\lambda)$	is the value of scotopic spectral luminous efficiency at λ_0 = 555 nm
	a,b are parameters with values *a* = 0,7670 and *b* = 0,3334

Then it is possible to describe functions in order to determine the relevant values and be applicable to CIE system for mesopic photometry described in the document CIE 191:2010 by relations (1) and (2). Into both of relationships (1) and (2) are needed to know values of luminances which can be determined for example from photometric measurement or assuming these parameters from photometric data of luminaire used in the calculation.

Adaptation luminance

Currently the most of research work in the mesopic photometry field is focused on establishment appropriate methods how to determine adaptation luminance. Assuming drivers at outdoor lighting conditions the light scene in the field of view of the observer is diverse due to different objects with various luminance levels, moving objects etc. All these things influence also adaptation state of visual system of the observer. It should be noted that only determination of adaptation luminance prevents implementation of the recommended system for mesopic photometry into the practice. Therefore nowadays they are addressed in the various research projects as problems regarding the establishment of areas of adaptation of visual system in the field of view of the observer under the conditions of mesopic vision, to be taken into account for determining an adaptation luminance with respect to specific situations visual tasks of the observer under defined lighting conditions. Generally the determination of the adaptation luminance depends on the proper use of a particular spectral responsivity of the human eye to be considered. Then subsequent lighting calculations can use results of determination of adaptation luminance as well as they can serve as for appropriate measurement system of the mesopic photometric quantities. Taking account of these effects in different light conditions in the observer's field is still looking for a suitable system for clear identification of adaptation brightness. Described recommended system for mesopic photometry is based on model visual performance of the observer i.e. means taking into consideration the impact of the central and peripheral vision [8]. These visual tasks are most essential for lighting conditions of outdoor lighting systems at night driving a car. The car driver is subject to different visual tasks, which in the process of vision lighting conditions, external lighting systems occur. Under these conditions have to be considered processes of the visual system which directly affecting visual perception. They are based on the consideration of luminance contrast of the observed objects to the brightness of the background, which exactly corresponds to the vision-performance and not to the contrast of brightness of objects in the visual field of the observer. The basic visual tasks are based on three fundamental issues as follows

a) Can the object in the visual field observer clearly recognized
b) How fast can the observer recognize the subject
c) What is the object in the visual field of the observer?

All of these questions should be assumed at determination of adaptation luminance. Recently new approach about of calculation of adaptation luminance based on analysis of luminance distribution of light scene measured by image photometer was developed in Japan [4]. It takes into account all three assumptions as answers on the questions above i.e. direction of line of sight of observer, area for which will be computed photometric parameters, surrounding luminance effect, luminance distribution of the scene and area under consideration to be illuminated. These aspects are described by means of the functions LD (luminance distribution), EM (eye movement), SLE (surrounding luminance effect) and AOM (area of measurement). All of these functions are assumed to be independent. Each of this function is based on coordinate system of eye retina of observer and object plane described by two angles φ,ϑ. This coordinate system is depicted in the picture Fig.1.

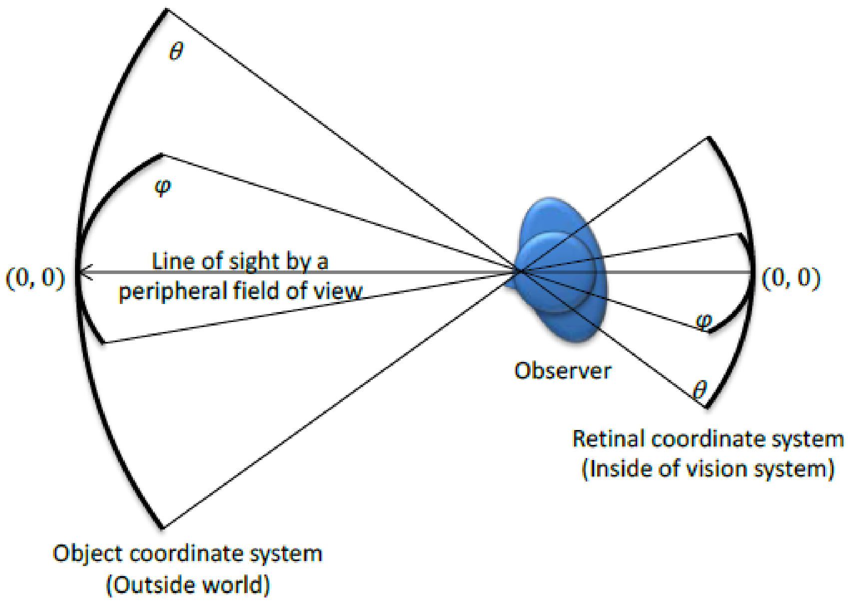

Figure 1 – Object and retinal coordinate system of the observer [4]

The simulation method to calculate the adaptation luminance consists of the following four steps.

1. Effective luminance distribution calculation

2. Adaptation luminance distribution calculation

3. AOM hit probability distribution calculation

4. Adaptation luminance calculation

By means of convolutions of described functions LD, EM, SLE and AOM in combination with integrations (see reference [4] for more details) the adaptation luminance of AOM, which is the average adaptation luminance weighted with the AOM hit probability distribution, is derived as

$$L_{a,AOM} = \frac{\iint L_a(\theta,\varphi).P_{AOM}(\theta,\varphi)\mathrm{d}\varphi\mathrm{d}\theta}{\iint P_{AOM}(\theta,\varphi)\mathrm{d}\varphi\mathrm{d}\theta} \quad (3)$$

In Japan were investigated 16 light scenes of walksides and park areas [4]. For each area was calculated adaptation luminance from luminance distribution obtained by image photometer based on CCD element. From the luminance distribution of the scene was calculated adaptation luminance for each area of interest which was illuminated by different luminaires.

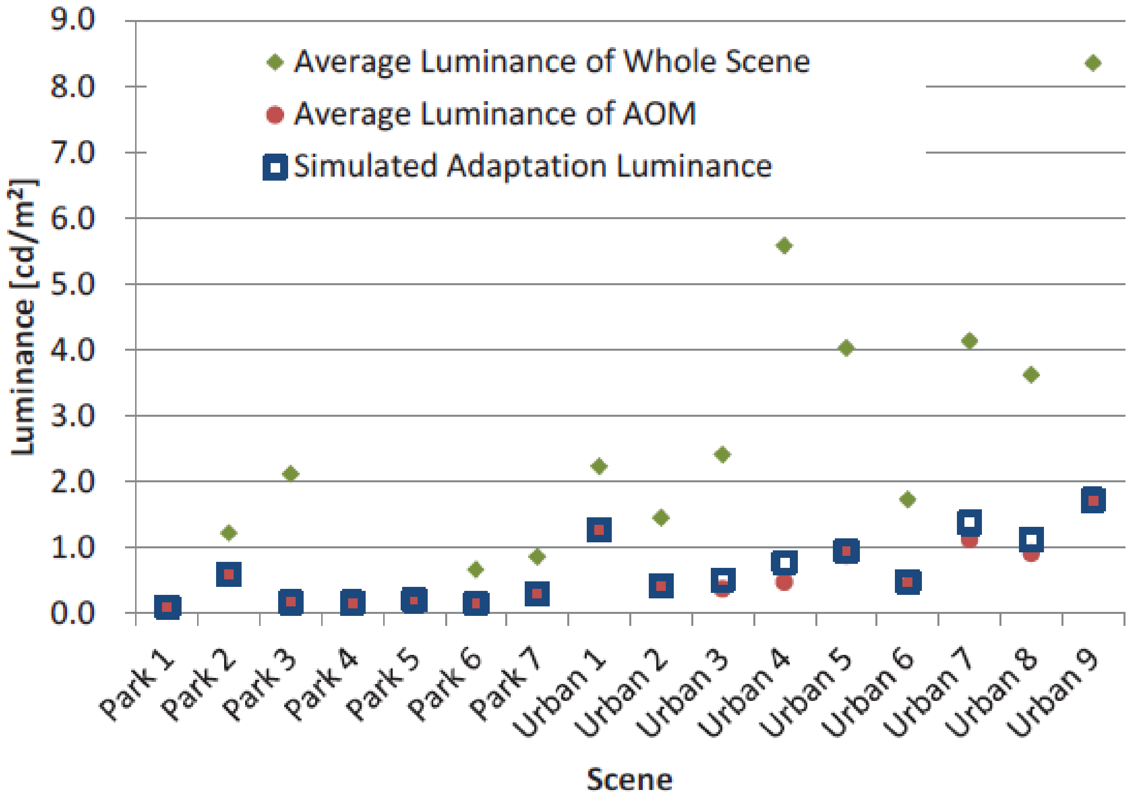

Figure 2 – Simulated adaptation luminance / small EM [4]

After the calculation based on the proposed model was found good predictor which can be used for determination of adaptation luminance directly from luminance distribution. Investigation was made for different EM functions which describes the measure of eye movement by means of two dimensional Gaussian functions. Consideration was done for small, medium and large change of the line of sight of the observer (Figure 2, Figure 3 and Figure 4).

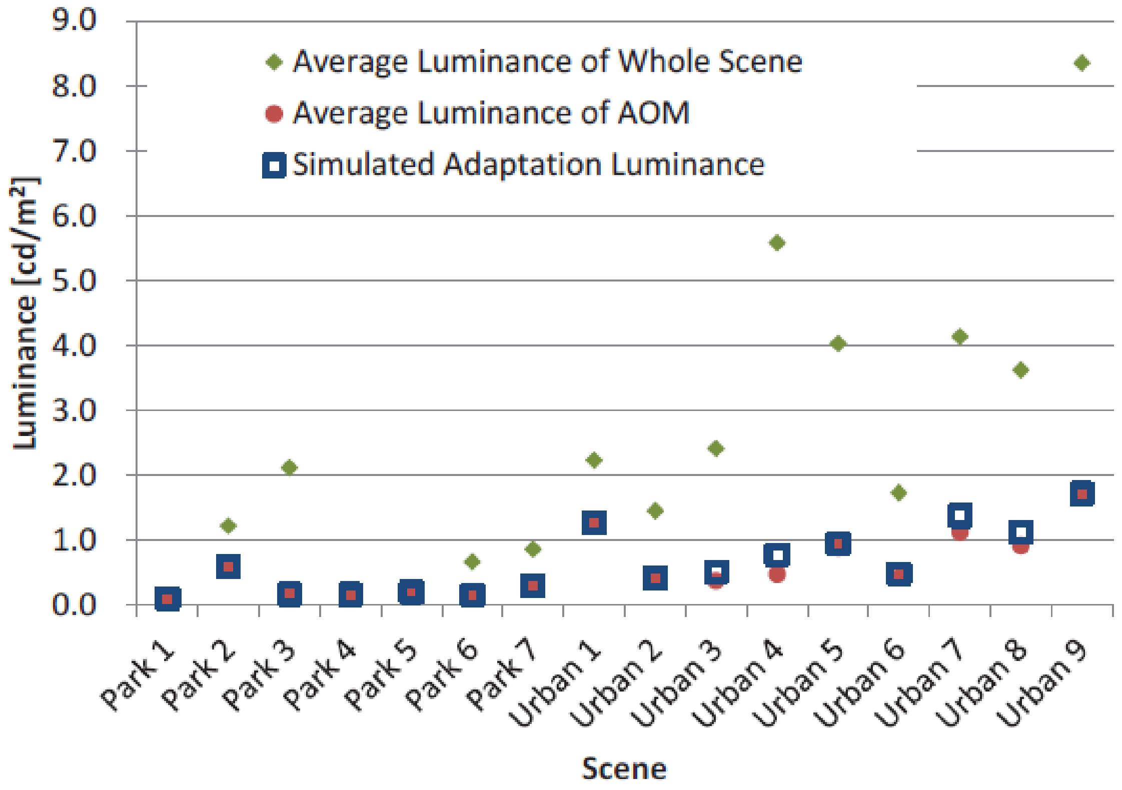

Figure 3 – Simulated adaptation luminance / medium EM [4]

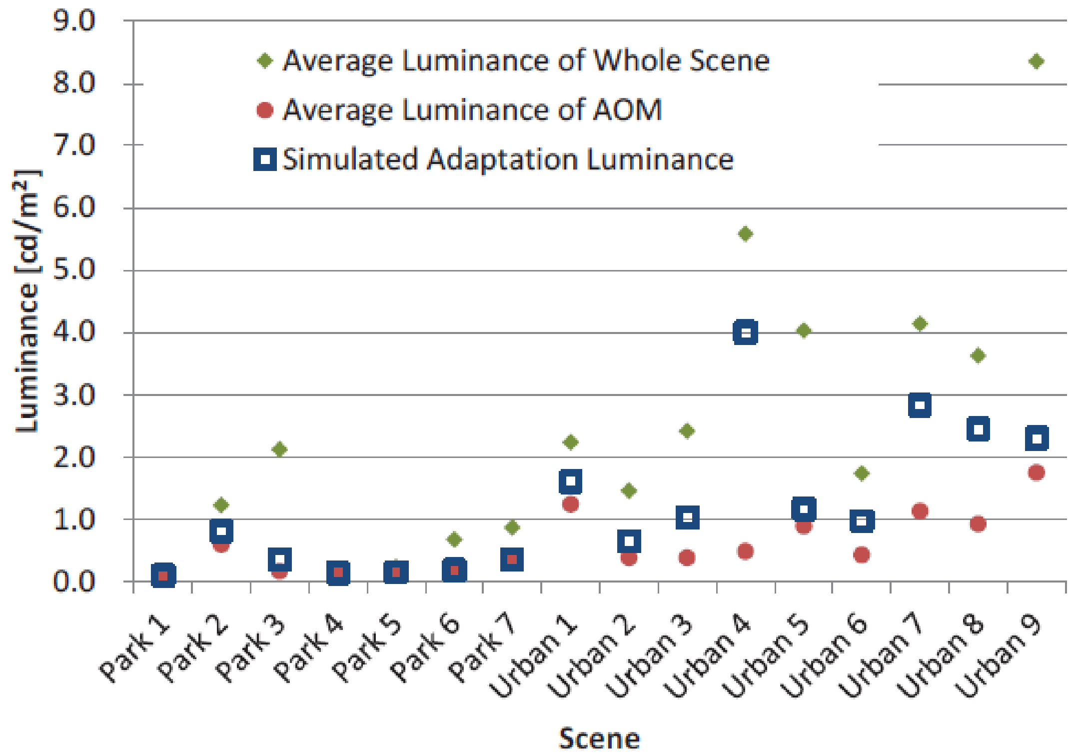

Figure 4 – Simulated adaptation luminance / large EM [4]

In the graphs of the simulation results are depicted also predictors which can be used as directly for determination of adaptive luminance without following of complex mathematic process. As good predictor of adaptation luminance seems avaregae luminance of area of interest to be illuminated (AOM) for small and medium EM, but for large EM it was shown that for some areas it does not match so well with calculation of adaptation luminance. Therefore it should be investigated in more detail for other scenes and various EM functions.

CCD Spectroradiometers

Usually in laboratories are used spectroradiometers using grid as disperse element in Czerny-Turner geometry. On the market we can find lot of types of spectroradiometers with different construction and different detection system consist detectors with various spectral responses. In mesopic photometry should be used spectroradiometers which are simply portable and spectral information over whole spectral region to have on real time instead of scanning wavelength by wavelength i.e. time consumable measurement. This advantage provides still forthcoming and improving spectroradiometers with CCD array detector. CCD array element has area where are small areas so-called pixels defining resolution of instrument. For each pixel belong wavelength region with some bandwidth. Scheme of CCD array chip with photo can be seen on picture Figure 5.

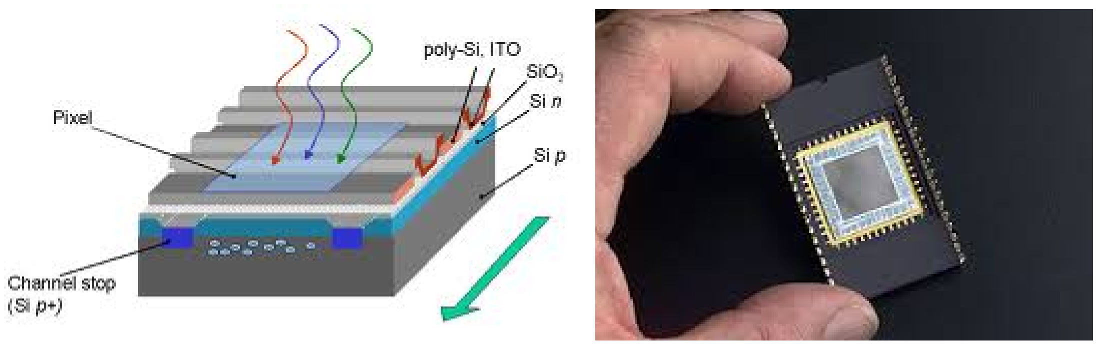

Figure 5 – CCD array detector

These detectors are mounted into CCD spectroradiometers which can have different construction for example spectroradiometer with optics, fiber CCD spectroradiometers (Figure 5) and so on. On CCD array detector falling radiation from source through optical system which is divided into wavelengths by diffraction on the grating. As output from detector is electrical signal caused by falling photons on detector from source. For this electrical signal each pixel has defined some responsivity what converts to spectral radiometric units as mentioned before radiant flux, irradiance or radiance.

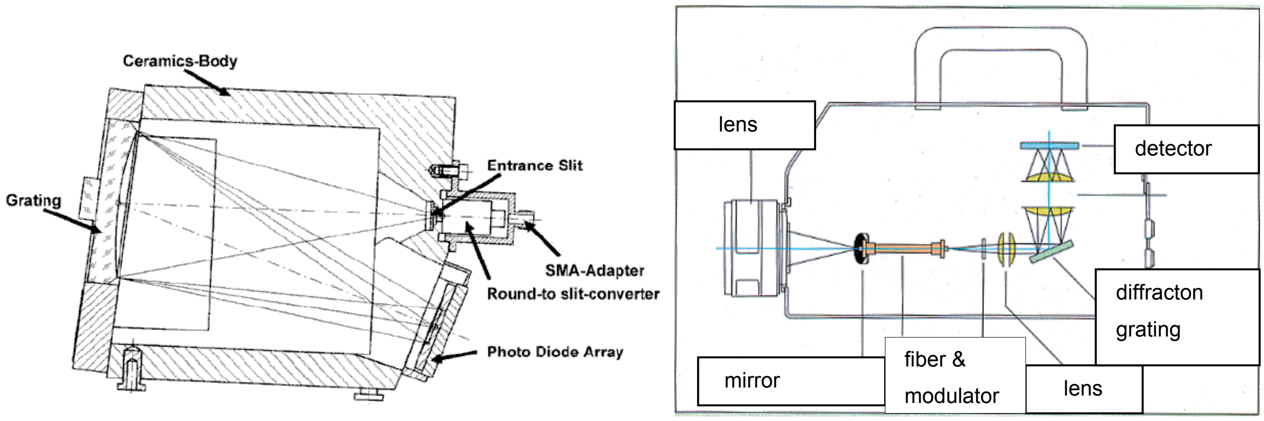

Figure 6 – Examples of CCD array spectroradiometers

More and more users like use fiber spectroradiometers what is compact solution for many measurements because this it is easy portable due to its dimension in comparison with other devices. Using of fiber CCD spectroradiometers can be simply constructed radiance meter which can be used for photometric measurement also in mesopic region. As it was mentioned above for mesopic photometry should be determined scotopic and photopic luminances for computing mesopic photometric quantities. Spectroradiometers can be used as devices which measures spectral radiometric quanity and integration over spectral region using spectral luminous efficiency functions can be found out values of these luminances. For these devices emerges another problem about proper radiometric characterization by means of calibration. The process of calibration under mesopic conditions is described in the paper [6].

Illuminance meter based on CCD Spectroradiometer

Based on the principles of determination of adaptation luminance it can be calculated adaptation level luminance. Furthermore it can be chosen mesopic spectral responsivity of and this function can be used as function for calculation of illuminance level based on spectroradiometer by installing cosine diffuser on the input entrance of fibre. The determination of adaptation luminance can be evaluated from luminance distribution acquired by image photometer. Example of luminance distribution of AOM from practice is depicted in the picture Figure 7.

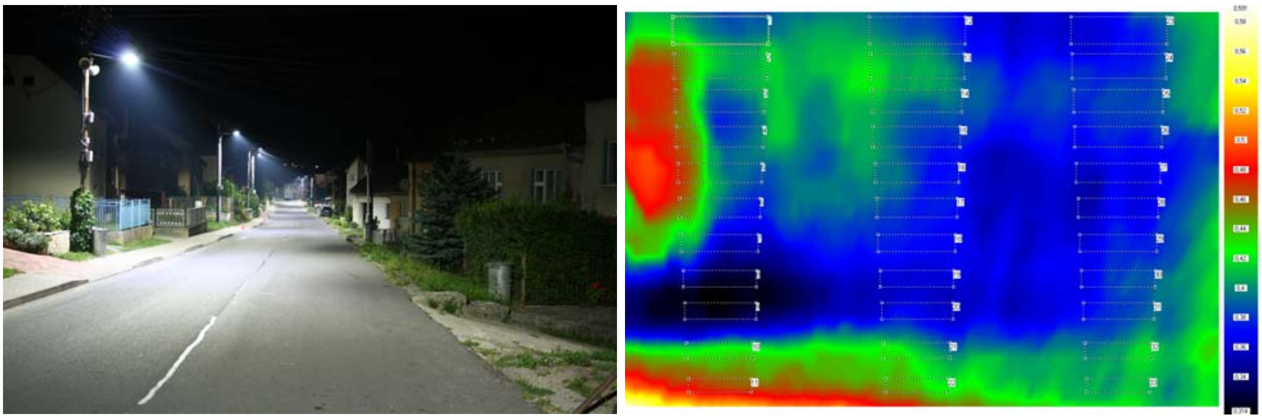

Figure 7 – ME5 road class – photo and luminance distribution of AOM

The determination of adaptation luminance for example of ME5 road class was performed assuming of average luminance of AOM as it was decribed above with assumption of small or medium EM funtion. After that was stated spectral responsivity function of observer for determined adaptation luminance level. This function is used for measurement of illuminance level of the outdoor lighting for assessment mesopic illuminance level under specified conditions and roadlighting system geometry. Even more this function can be used for measurement of luminance level based on spectroradiometry where filter errors are avoided.

Conclusions

In the paper was described possibility to use array spectroradiometers under mesopic conditions as illuminance meter by which can be measured illuminance level under mesopic conditions assuming adaptation luminance level according to the theoretical background of determination of proposed system. In the future it would be needed perform measurements of more roadlighting situation with different luminaires and improve of software tool for mesopic photometer based on CCD array spectroradiometer for field trials for outdoor applications everywhere is mesopic photometry relevant.

Acknowledgments

This publication is the result of the project implementation:
Research centre of light and lighting technology, ITMS 26220220150,
supported by the Research & Development Operational Programme funded by ERDF.

Operačný program VÝSKUM a VÝVOJ

Agentúra Ministerstva školstva, vedy, výskumu a športu SR pre štrukturálne fondy EÚ

Podporujeme výskumné aktivity na Slovensku/
Projekt je spolufinancovaný zo zdrojov EÚ

Európska únia
Európsky fond regionálneho rozvoja

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