Mesopic photometry using spectroradiometric means

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Abstract

Spectroradiometry is the process of making traceable radiometric measurements on a wavelength-by-wavelength of the source emitting radiation basis using an instrument called a spectroradiometer. It is very important because by means of spectroradiometer user can have complex information about source under investigation. Therefore spectroradiometers are broadly used for spectral investigation of the sources. Such investigation is very important also in the photometric measurements especially when from spectral radiometric quantities user wants to compute photometric quanitities. Spectroradiometers are more precise than filter photometers which have spectral mismatch error which significantly can influence results of measurements. On the other hand spectroradiometers are more expensive than filter photometers therefore they are not used so frequently. Recently at the CIE level (Commision Internationale de l'Eclairage) was started work about mesopic photometry. It is region between photopic and scotopic vision where sensitivity of human eye changes dynamically depending on luminance level. Direct measurement of radiometric quantities can be advantage for use of spectroradiometers in the mesopic region. Paper concerns recently started work and preliminary results for investigation of possibility to use spectroradiometers for photometric measurements under mesopic conditions.

Keywords: Mesopic photometry, Spectroradiometry, CCD Spectroradiometers

Introduction

Once has been measured spectrum then according to philosophy of mesopic photometry is needed from the measurement results determined scotopic and photopic luminance. The basic requirement is to have instrumentation calibrated to radiometric quanities radiance or irradiance. This provides spectroradiometer which can provide results of measurement in spectral radiometric values that can be integrated over the visible wavelength region weighted by $V(\lambda)$ and $V'(\lambda)$ functions in order to determine the relevant values and be applicable to CIE system for mesopic photometry described in the document CIE 191:2010 Recommended System for Photometry Based on Visual Performance [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 $V_{mes}(\lambda)$ attains a maximum value of 1
L_{mes} is mesopic luminance
$V_{mes}(\lambda_0)$ is the value of $V_{mes}(\lambda)$ at the 555 nm
$L_e(\lambda)$ is the spectral radiance in W.m^{-2}.sr^{-1}.nm^{-1}

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

$$m_0 = 0{,}5$$

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

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

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

Into both of relationships (1) and (2) are needed to know values of luminances which can be determined from photometric measurement. Luminance meter constructed from filter photometers has been already done in frame of work EMRP project Metrology for Solid State Lighting [2]. Other possibility how to measure luminances for mesopic photometry is using of image photometers which are portable and from measurement by these instruments can be easily determined appropriate field of view. Usage both of described devices has one disadvantage there is no spectral information exists. Furhermore errors from mismatch filter curves from defined curves in photometry can also significantly influence results of measurement of mesopic photometric quanities. Therefore spectroradiometers can be used for these measurements to avoid mismatch errors and additionally to have spectral information.

Instruments in spectroradiometry

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 1.

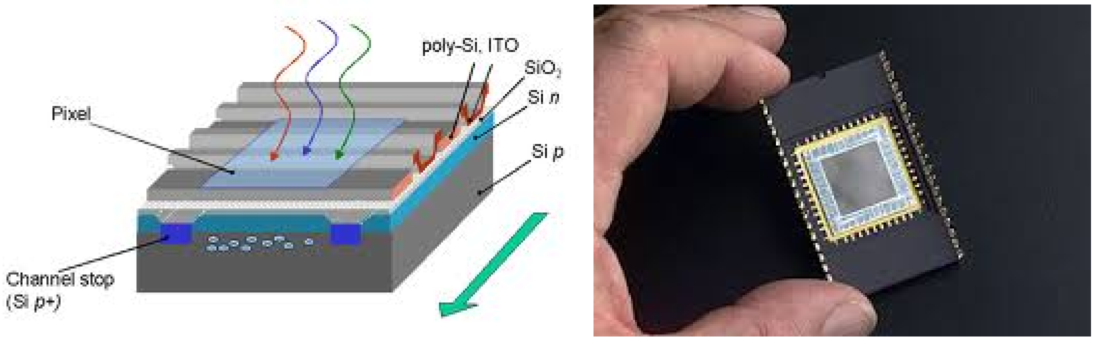

Figure 1 – CCD array detector

These detectors are mounted into CCD spectroradiometers which can have different construction for example spectroradiometer with optics, fiber CCD spectroradiometers 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. 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. Principle of detection of CCD array fiber spectroradiometer is depicted on Figure 2.

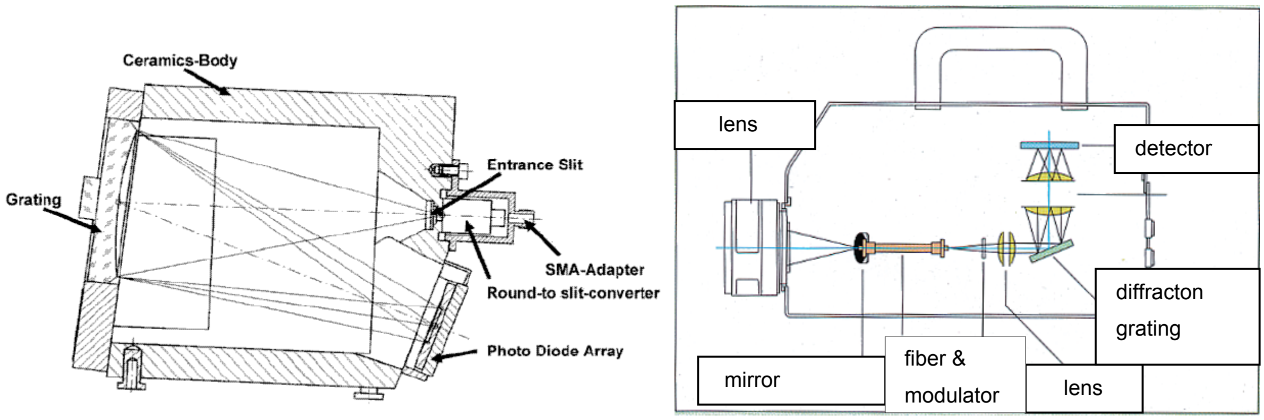

Figure 2 – Examples of CCD array spectroradiometers

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.

Calibration of spectroradiometers

In previous section was introduced types of spectroradiometers which can be possible used for photometric measurements even more in mesopic region. In further text attention will be focused on array spectroradiometers. For these spectroradiometers it is needed to perform proper calibration to ensure reliable results from spectroradiometric measurements. Because user need to measure spectral absolute values it should be performed calibration for these radiometric quantities which will be considered in further processing of results of measurement. For mesopic region it is desirable to know luminances as it was mentioned above i.e. scotopic and photopic luminances. This can be achieved when spectroradiometer is calibrated to radiometric unit radiance and simply integration over two functions for scotopic and photopic observer can be computed both luminances from measurement of spectral radiance. Before calibration is also needed to correct some negative factors which can negatively influence results of measurement. Firstly wavelength calibration of spectroradiometer before measurement should be done by line sources to check e.g. mercury, neon, argon lamps etc. In spectroradiometers results can be negatively also influenced by stray light what is the term used to refer to the minute amount of unwanted light having wavelengths outside the narrow band isolated by the optical system. It comprises for example scattering from diffraction grid, affected of output signal by higher diffraction orders and so on. Further characterization of spectroradiometers bandwidth correction is needed to minimise the error introduced by instrumental bandpass functions on spectrally integrated or weighted quantities. This can be done by applying method recently presented by paper [3] which allow user to correct both stray light and bandpass effects simultaneously. At the end of calibration process of spectroradiometer Is to calibrate output signal of detectors to radiometric quantities. For luminance measurement is good to have calibrated spectroradiometer to radiance units. CCD spectroradiometer should has appropriate optics to determine field view for measurement. Optics of spectroradiometer consists from baffles and other additional optical parts which precisely define investigated area. Fibre CCD spectroradiometer modificated for measurement of radiance is described in paper [4] [5]. Example of this motorized measurement apparatus is depicted on Figure 3.

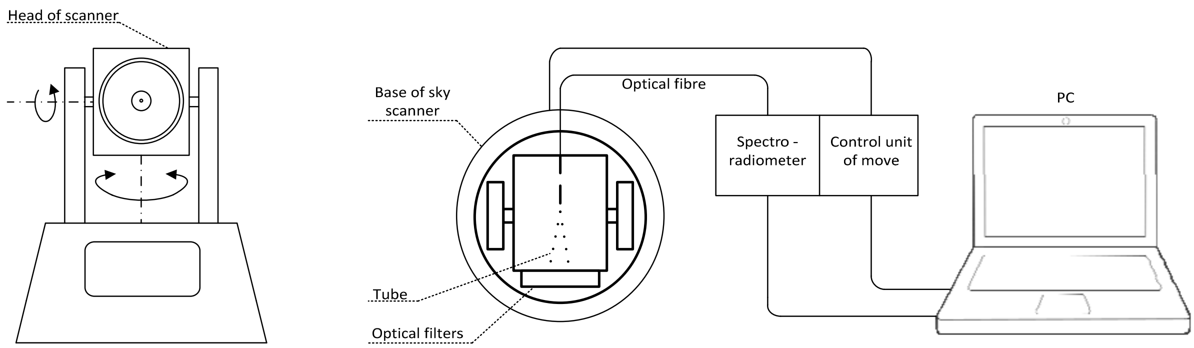

Figure 3 – Scheme of apparatus for measuring radiance measurement

It is system where fiber is inserted into motorized tube with optical system determined particular field of view which is controlled by computer through USB interface. Subsequently device can be calibrated for spectral radiometric quantity corresponding to photometric quanitity luminance e.g. radiance ($W.m^{-2}.sr^{-1}.nm^{-1}$). Calibration on spectral radiance can be performed by white plate diffuser. Proces should be performed for different irradiance levels to check linearity of instrument. Spectroradiometer measures primarily irradiance falling on the entrance of fibre optics. Relation between irradiance and radiance can be stated according to equation (3).

$$L_{\mathrm{e}}(\lambda) = \frac{\rho(°0/°45,\lambda)}{\pi} . \left(\frac{d_{\mathrm{ref}}}{d}\right)^2 . E_{\mathrm{e}}(\lambda) \qquad (3)$$

where

$\rho(\lambda)$ is the spectral reflectance factor of diffuser plate;
d is the measured distance between the lamp and plate;
d_{ref} is the reference distance between the lamp and plate;
$E_e(\lambda)$ is the spectral irradiance in W/m^2;

This procedure needs to have calibration standards to be traceable to national standards spectral irradiance in combination white plate with known spectral reflectance. Usually for process of calibration are used as standards tungsten light sources for example FEL 1000W. It shall be used source with appropriate spectral and level of radiation composition depending on the usage.

Spectroradiometer under mesopic condition

In first section was described theoretical background for mesopic photometry. According to relationships (1) and (2) spectroradiometric measumrent can be used for determination of radiance, scotopic luminance and photopic to determine mesopic luminance. In previous section was described calibration of spectroradiometers to spectral radiometric units radiance $L_e(\lambda)$. Mesopic region lie between scotopic and photopic region and assessed between luminances levels 0,005 cd.m^{-2} to 5 cd.m^{-2}. It means that for calibration follows relation (3) would be needed low level source for calibration of spectroradiometric system. At the present if it is considered that photopic luminance level for road lighting is between 0,3 cd.m^{-2} to 2 cd.m^{-2} what is the most often mesopic region considered in photometry for calibration respect lambertian law would be needed source depicted on Figure 4 under consideration that it is typical tungsten light source supplied by constant current source.

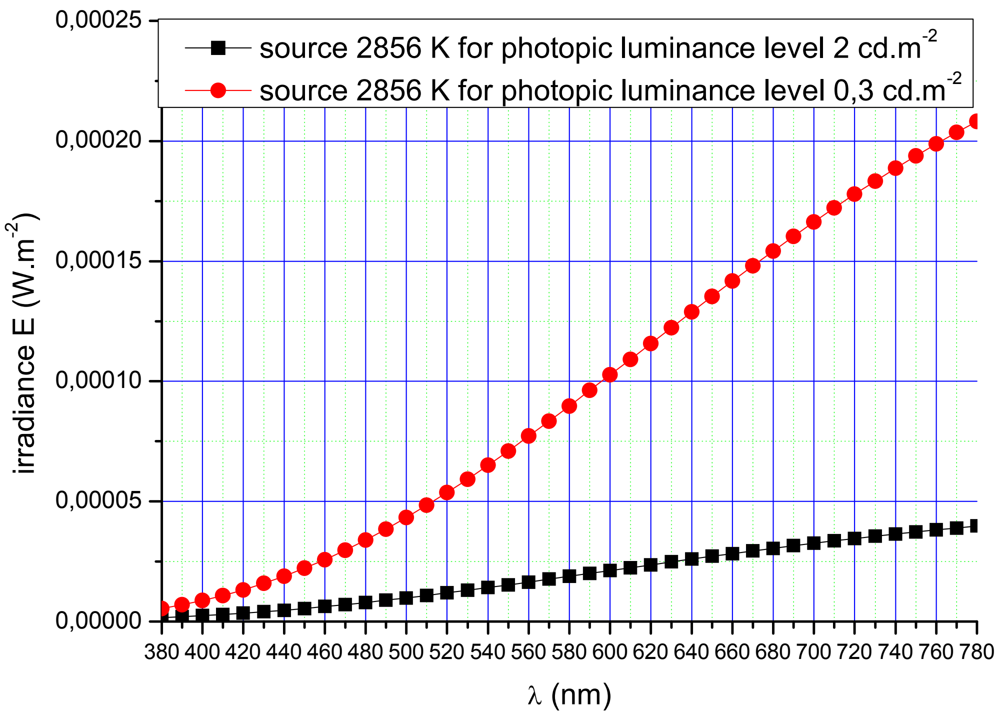

Figure 4 – Spectral irradiance level for calibration of spectroradiometer for mesopic region

It was assumed that calibration would be performed with usual calibration plate from PTFE or $BaSO_4$ material with Lambertian surface and known spectral reflectance $\rho(\lambda)$. Due to lower level of spectral irradiation It should be taken care about electrical noise dark signal of spectroradiometer. It means signal to noise ratio should be so sufficient to measure that low signal. On the market exists spectroradiometers which high S/N ratio to be able measure low luminances ensured by cooling of CCD chip. When spectroradiometer is properly calibrated on luminance levels then should be solved another issues still to be resolved in the near future. At CIE level JTC001 concern with mesopic photometry focused on outdoor lighting. It is joined technical committee which includes experts from different fields. The biggest issue and at the present mostly under investigation is what field of view of observer should be used in mesopic photometry. Simultaneously is investigating where attention of observer is focused by means of image luminance meters in combination with eye-tracking technology. Also diameter of pupil and eye tasks for observers under mesopic conditions is under investigation in present. After that it can be possible to determine adaptation luminance level which as it is considered can differ for different situations.

Conclusions

In paper was described possibility to use array spectroradiometers under mesopic conditions as spectral radiance meter from which can be derived according to theoretical background mesopic quantities. Main problem remain on investigation as it was described above still running in present of determination of field of view which influence also measuring system in mesopic photometry. In the future according to result at Slovak University of Technology is plan to construct mesopic photometer based on CCD array spectroradiometer for field trials for outdoor applications and everywhere is mesopic photometry relevant.

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