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Research and development of a luminance responsivity standard system at the Vietnam Metrology Institute

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Abstract:

The development of a luminance responsivity standard is central to the study of photometry and radiometry at the Vietnam Metrology Institute (VMI). Today, two methods are used to determine luminance responsivity. The first method uses an integrating sphere light source, also known as a luminous intensity standard lamp, and the second method compares the luminance responsivity value to that of a known standard photometer. Using these methods, it is possible to identify small uncertainties. In this work, we analysed the luminance responsivity standard system (model: VMI-PR-006) based on the national standard system of luminance (model: V11.04.18). This system was used to calibrate the luminance responsivity scale of standard photometer and luminance standard integrating sphere.

When using the national standard system (V11.04.18) to calibrate the luminance standard integrating sphere (model: LN3; S/N:05B840), an uncertainty of U=0.73% for k=2, where k is the *, was found [1]. On the other hand, we calibrated the luminance responsivity scale of a standard photometer system (VMI-PR-006) based on the national standard system of luminance (V11.04.18) and compared it to the luminance responsivity scale calibrated at NMIA (National Measurement Institute Australia) with E_n=0.13<1, where E_n is *. This standard system is used for the calibration and verification of measurement devices within the luminance measurement requirements specified by the Vietnam technical documents.

Keywords: **luminance meter, luminance responsivity scale (A/(cd/m^2)), luminance standard integrating sphere source, photometry and radiometry.**

Classification number: **2.1**

Introduction

Luminance responsivity is a photometric quantity that realizes the brightness of a surface. Recently, a luminance responsivity scale has been presented [2, 3], which is based on a separate measurement of the spectral responsivity, as well as the distance and size of the aperture. The luminance responsivity value at the aperture plane of an integrating sphere is obtained from the measurements. In this work, we present our analysis of the unit of luminance responsivity.

This investigation, conducted at VMI, determines the unit of luminous intensity using a luminance integrating sphere source, a reference standard photometer, the distance and the size of the aperture, and a spectroradiometer. The method for determining the unit of luminance responsivity is comparable to that of the luminous intensity value. In addition, the area of the output aperture of the sphere must be known, as described in Refs. [2, 4, 5]. We present a newly developed method for separately measuring the spectral responsivity, the distance, and the size of aperture as described.

Measurement setup and realization of unit

Measurement setup

The measurement setup consisted of a reference standard photometer, a spectroradiometer, a luminance integrating sphere, and an optical bench. During the measurements, the integrating sphere, the reference standard photometer, and the spectroradiometer were placed on an optical bench.

The optical bench is shown in Fig. 1. The optical axis was determined by an alignment laser. The alignment laser is used to align and setup the luminance integrating sphere on the optical bench, where the optical axis is perpendicular to and passes through the centre point of the open aperture

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of the luminance integrating sphere. The fixed location of the luminance integrating sphere determined the optical axis to be at a height of 55 cm above the surface of the optical bench. The optical axis was visualized by using a two-beam alignment laser positioned between the reference standard photometer and the integrating sphere.

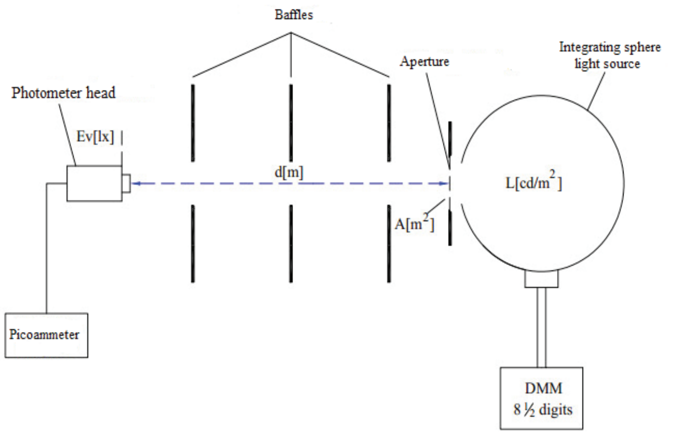

Fig. 1. Principle of the measurement set-up for realization of the unit of luminance responsivity.

The diameter of the aperture of the reference standard photometer was 30 mm. The photocurrent of the photometer was measured using a high precision picoammeter. The aperture diameter of the luminance integrating sphere was 70 mm. The luminance integrating sphere, which was coated with barium sulphate paint, was illuminated by a tungsten halogen lamp. The operating current of the lamp was chosen such that the correlated colour temperature of the source was 2856 K. The distances between the aperture plane of the integrating sphere and the reference standard photometer were measured by a length scale [3-6], in Fig. 2.

Fig. 2. Photograph of the typical luminance measurement setup.

The reference standard photometer was then moved to the appropriate measurement distance, which was determined by a length scale. The distance between the front surface of the aperture holder and the aperture plane of the integrating sphere source was measured mechanically.

Luminance responsivity calibration

The luminance responsivity of the reference standard photometer was determined from the measurement geometry and the illuminance measured with a reference standard photometer [4]. The luminance of the integrating sphere and luminance responsivity of the reference standard photometer were obtained from:

$$L_V = \frac{E_V \cdot D^2}{A_S} \quad (1)$$

where L_V is the luminance, E_V is the illuminance at the effective distance, D, between the aperture planes of the source and the standard photometer, and A_S is the area of the light source aperture.

The luminance responsivity is obtained from:

$$S_L = \frac{S_V . A_S}{D^2} \quad (2)$$

where S_L is the luminance responsivity in A (A/(cd/m^2)) and S_V is the illuminance responsivity of reference photometer (A/lx). The effective distance, D, depends on the radius of the photometer aperture, r_D, the radius of the source, r_S, and the physical distance, d, between the two apertures according to the relation:

$$D = \sqrt{d^2 + r_D^2 + r_S^2} \quad (3)$$

Equation (3) is accurate within ±0.01% for distances that are at least one order of magnitude greater than the radii of the two apertures [4, 5].

The illuminance was measured at a distance greater than 2500 mm. The luminous intensity of the source was determined only at the luminance level and correlated colour temperature of 2856 K. The lower luminance levels were determined by measuring the changes in illuminance, with the photometer placed close to the aperture plane of the integrating sphere.

Because spatial uniformity is a crucial factor, we investigated the non-uniformity of the output aperture of the integrating sphere. The non-uniformity of the integrating sphere is shown in Fig. 3.

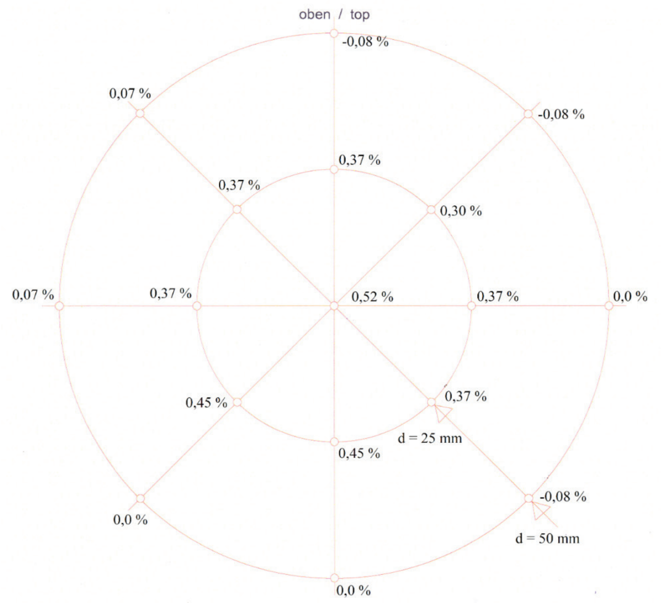

Fig. 3. Non-uniformity of output aperture surface of the integrating sphere.

The luminance of the integrating sphere and related analyses require corrections, thus, correction factors were calculated for all measurements. Calibration report data of the luminance used by the luminance responsivity of reference standard photometer is shown in Table 1.

Table 1. Calibration report data of the luminance (cd/m²).

No.	Photocurrent values, nA	Standard illuminance values, E_V (lx)	Calibrated luminance responsivity of reference standard photometer, S_L (A/(cd/m²))	Luminance of integrating sphere (LN3-05B840 at VMI, L_v (cd/m²)
1	63.184	4.090	4.819×10^{-11}	1311.1
2	63.187	4.090	4.819×10^{-11}	1311.2
3	63.182	4.089	4.819×10^{-11}	1311.1
4	63.185	4.090	4.819×10^{-11}	1311.2
5	63.184	4.090	4.819×10^{-11}	1311.1
Avg.	63.184	4.090	4.819×10^{-11}	1311.1

The luminance of integrating sphere measured at VMI (Vietnam) and PTB (Germany) are given in Table 2.

Table 2. The luminance of integrating sphere measured at VMI (Vietnam) and PTB (Germany).

Luminance integrating sphere	Correlated colour temperature, K	Luminance of integrating sphere, L_v (cd/m²)		Absolute differences, ΔL_v
		VMI	*PTB*	*(VMI/PTB) - 1*
LN3-LMT; 05B840	2856	1311.1	1311.3	-0.00015

The maximum total luminance difference between the measurements at VMI and PTB, calculated as (VMI/PTB) - 1, of the integrating sphere was -0.00015, as seen in the Table 2.

The luminance responsivity of the reference standard photometer from the VMI and NMIA systems are given in Table 3.

Table 3. Luminance responsivity of the reference standard photometer based on the national standard system.

Reference standard for luminance responsivity of photometer	Correlated colour temperature, K	Luminance responsivity of reference standard photometer, S_L (A/(cd/m²)		Absolute differences, ΔS_L
		VMI	*NMIA*	*(VMI/NMIA) - 1*
VMI.PR006 (VMI)	2856	4.819×10^{-11}	4.827×10^{-11}	0.0017

The maximum luminance responsivity absolute difference between VMI and NMIA, (VMI/NMIA) - 1, of the reference standard photometer was 0.0017 as seen in Table 3.

Uncertainty analysis

Table 4 presents the results of the uncertainty analyses for the determination of the unit of luminance responsivity. All known uncertainty components were included. Detailed uncertainty analyses for the realization of the unit of illuminance responsivity may be found in Refs. [6, 7].

Table 4. The uncertainty analyses for the realization of the unit of luminance responsivity.

Components	Description	Rel. std. uncert., $u_r(x_i)$	Prob. distrib.	Sens. coef., c_i	Contrib. $c_i u_r(x_i)$, (%)	DoF
$u(S_v)$	Uncertainty of reference standard photometer	0.035	Nor	71	0.19	∞
$u(y_L)$	Standard uncertainty of the photocurrent measurement	0.015	t	206	0.24	2385
$u(y_L)_{rep}$	Uncertainty in repeated measurements	0.0030	t			4
$u(y_L)_{res}$	Uncertainty in the resolution	0.000029	Rect			∞
$u(y_L)_{inst}$	Uncertainty of the picoammeter	0.015	Nor			∞
$u(d)$	Standard uncertainty in the measurement distance	0.0012	t	689	0.064	920
$u(d)_{rep}$	Uncertainty in repeated measurements	0.00032	t			4
$u(d)_{res}$	Uncertainty in the resolution	0.00029	Rect			∞
$u(d)_{inst}$	Uncertainty in instrument distance	0.0012	Nor			∞
$u(r_a)$	Standard uncertainty in the open aperture of integrating sphere	1.5×10^{-6}	t	75806	0.01	∞
$u(r_a)_{rep}$	Uncertainty in repeated measurements	0.00	t			4
$u(r_a)_{res}$	Uncertainty in the resolution	2.9×10^{-9}	Rect			∞
$u(r_a)_{inst}$	Uncertainty of the CMM	1.5×10^{-6}	Nor			∞
$u(r_d)$	Standard uncertainty in the diameter of reference photometer head	1.5×10^{-6}	t	3	3.3×10^{-7}	∞
$u(r_d)_{rep}$	Uncertainty in repeat measurement	0.00	t			4
$u(r_d)_{res}$	Uncertainty of the resolution	2.9×10^{-9}	Rect			∞
$u(r_d)_{inst}$	Uncertainty of the CMM	1.5×10^{-6}	Nor			∞
$u(c_t)$	Uncertainty of uncorrelated components	0.0011	t	1319	0.11	938
u_{repro}	Standard uncertainty of the measurement reproducibility	0.00044	t			24
$u_{stablity}$	Standard uncertainty of stability of the integrating sphere	0.001	Nor			∞
$u_{straylight}$	Standard uncertainty of stray light	0.024	Nor	1	0.024	∞
$u(y_{SL})$	Standard uncertainty of the photocurrent	0.064	t	0.00076	0.1	∞
u_c	Combined uncertainty		Nor		0.35	9586
U; $k=2$, $P=95\%$	Expanded uncertainty		Nor		0.70	

Conclusions

The luminance responsivity standard system was conducted by the Photometry and Radiometry Laboratory at the VMI and was used for the realization of the unit of luminance responsivity based on a separate measurement of the spectral responsivity, the distances, and the sizes of apertures as described above. The overall uncertainty related to this calibration was estimated to be 0.70% at k=2 at luminance level of 1300 cd/m^2.

This method is also capable of calibrating the transfer standard luminance meter and luminance light integrating source.

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The authors declare that there is no conflict of interest regarding the publication of this article.

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