Verification and accuracy check of luminance and illuminance measurements using a commercial IP camera applied as an HDR vision sensor

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Abstract

This study verifies and checks the accuracy of luminance and illuminance from high dynamic range images (HDRI) generated by a commercial IP camera compared to measurement devices. The statistical analysis indicates that measuring luminance using the calibration method with a luminance meter is comparable with measurement results using a luminance meter, with average relative error in the range of 5–23%, whereas illuminance measurement using the equation method is in line with the measurement using an illuminance meter, with an average relative error range of 1–11%. Regarding the accuracy of the HDRI method, using digital cameras is in the range of 5–27%, which is still acceptable.

Keywords: high dynamic range images; luminance; illuminance; IP camera; view sensor

1. Introduction

Since the development of digital cameras and their utilization as luminance mapping tools using the High Dynamic Range Imaging (HDRI) technique [1], HDRI has been applied for lighting environment studies such as analyzing luminance, illuminance, and glare for visual comfort, generating illuminance maps, and controlling room lighting [2, 3]. To generate luminance maps from HDRI, several methods and software have been developed such as Radiance, Photosphere, hdrgen, hdrscope, and Devebec algorithms using MATLAB or Python [4–6].

Recent studies explore the use of HDRI using digital cameras for building automation and real-time lighting and window blind control systems. [7] introduced an HDR vision sensor for a lighting control system using a developed digital camera to maintain visual and thermal comfort as well as reduce energy consumption. [8] presented a low-cost, window-mounted HDRI sensor with a wide fisheye lens as a daylight glare control system. [9] presented control strategies for lighting energy saving while satisfying glare constraints by using a calibrated fisheye lens digital camera for validating luminance mapping and glare measurements.

Similar to digital cameras, commercial CCTV cameras or IP cameras can be used to create HDRI images. CCTV or IP cameras have been used for surveillance or monitoring human activities. Designed CCTV cameras integrated with central control system and PIR sensors have been used to monitor teachers' and students' performance in the classroom [10, 11]. This paper presents a calibration and verification method for a commercial IP camera applied as a view sensor to generate illuminance and luminance values from HDRI.

2. Methodology

2.1. Experimental setup

A 360-degree fisheye Vivotek FE8174/74V network security camera (IP camera) was used as a view sensor. It was capable of recording eight 1920x1920 pixel RGB images simultaneously at multiple exposures with shutter time starting from 1/5–1/32,000 s within one minute. Two experiments were conducted. In Experiment 1, the IP cam was installed horizontally and in Experiment 2, the IP cam was placed vertically at a height of 1.2 m (Fig. 1). In each experiment, six HDRIs were created at different room brightness as dimmable LED lamps were used to provide

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different light brightness. During the experiment, a Konica Minolta LS-110 luminance meter and a Konica Minolta T-10/T-10M illuminance meter were used to calibrate and monitor the luminance and illuminance values, respectively. Eight papers were put on the floor (Fig 1a and 1b) or desk and wall (Fig 1c and 1d) as measurement points and one was used as the calibration point. The illuminance meter receptor units were placed next to each paper. Each measurement comprised 42 data points.

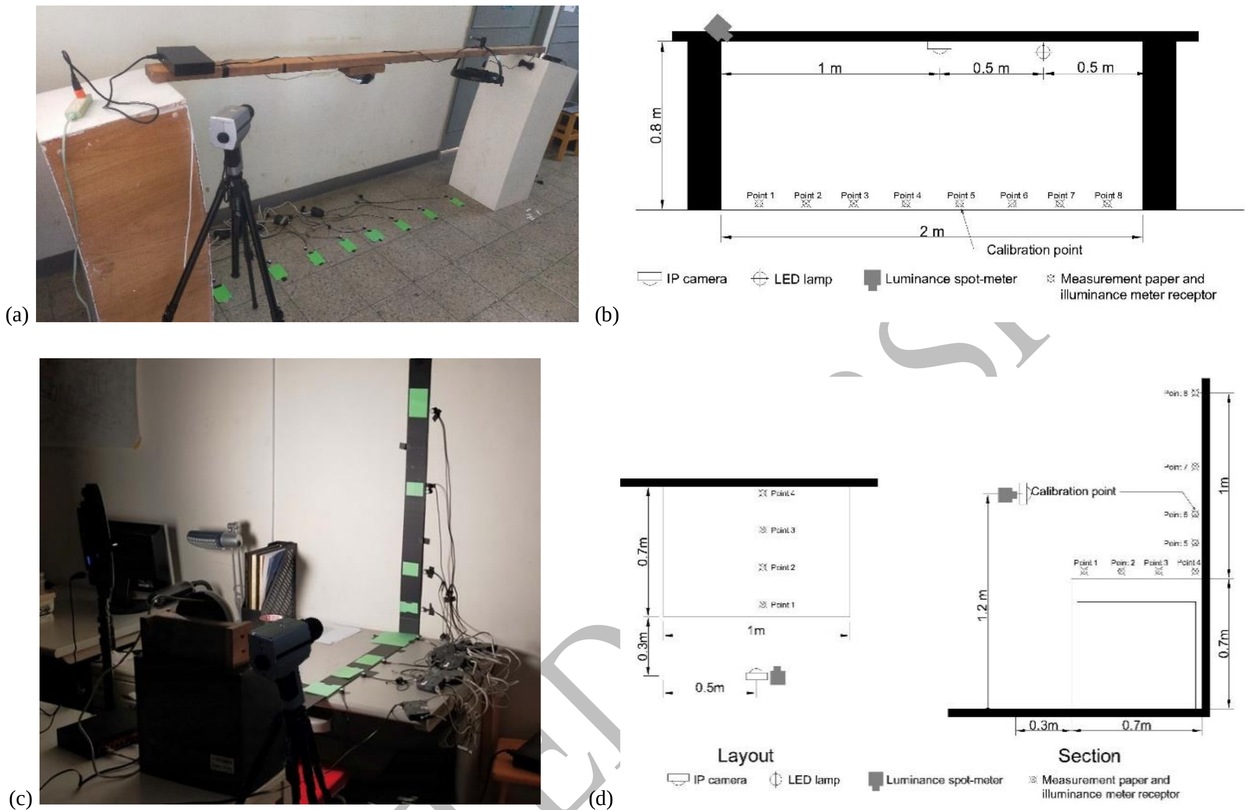

Fig. 1. (a) Experimental setup using an IP camera installed horizontally (Experiment 1); (b) Schematic representation of Experiment 1; (c) The IP camera was placed at ta height of 1.2 m (Experiment 2); (d) Schematic representation of Experiment 2.

2.2. HDRI processing

An HDRI was created by merging eight low dynamic images using the Debevec algorithm [6, 12]. To calculate the luminance value, the following equation was used:

$$L_{pixel} = (0.265 * R + 0.67 * G + 0.065 * B)$$

where L_{pixel} = luminance value of the pixel (cd/m^2); R, G, and B = the spectrally weighted radiance of the pixel (W/m^2 sr); and 0.265, 0.67, and 0.065 are calculated from CIE chromaticity used by Radiance [5, 13]. To obtain the luminance value of HDRI, a luminance meter was used to calibrate the luminance value of the pixels using the equation:

$$L_{HDRI} = k * L_{pixel}$$

where k = calibration factor obtained from the luminance value of the luminance meter divided by the luminance value of the pixel determined as the calibration point. This calibration factor varies for each measurement. This method is called “Method 1.”

In addition to using a calibration factor to obtain the luminance value, another method using the equation proposed by [7] was used. To test the equation, six measurement data were used as training data and six additional measurements were obtained as test data. The equation solved using the training data was then used to obtain the HDRI luminance value of the test data. This method is called "Method 2."

These two methods were used to obtain the HDRI illuminance value. For Method 1, the luminance value was converted using the equation:

$$E = (L/\rho) * \pi$$

where E = illuminance value (lux); L = luminance value of the pixel (cd/m^2); and ρ = reflectance of the surface, which was measured by Konica Minolta Spectrophotometer CM-2600d to be 0.657 [2]. For Method 2, the equation method proposed by [7] was used as explained earlier.

3. Results and analysis

The luminance and illuminance values obtained from HDRI and measurements were compared using relative error according to the equation:

$$\text{Relative error} = \text{abs}\left[(M_{HDRI} - M_{measurement}) / M_{measurement}\right] * 100$$

where M_{HDRI} = luminance/illuminance obtained from HDRI and $M_{measurement}$ = luminance/illuminance value measured using luminance/illuminance meter.

3.1. Experiment 1 measurement results

(a) (b)

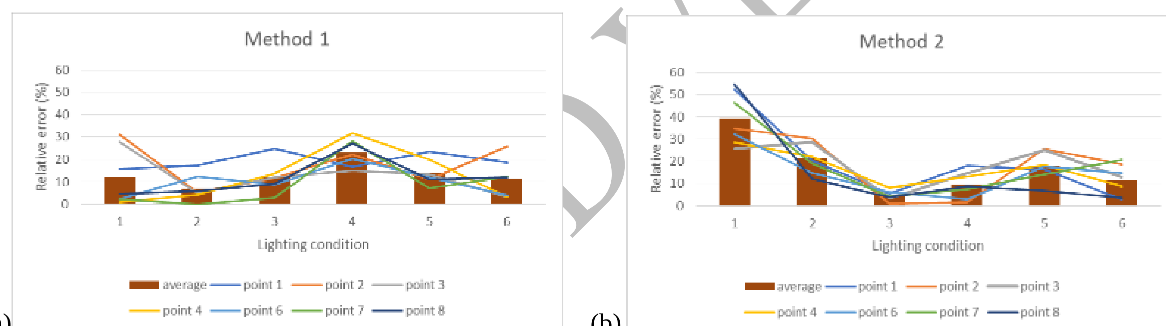

Fig. 2. (a) Luminance average relative error using Method 1; (b) Luminance average relative error using Method 2.

(a) (b)

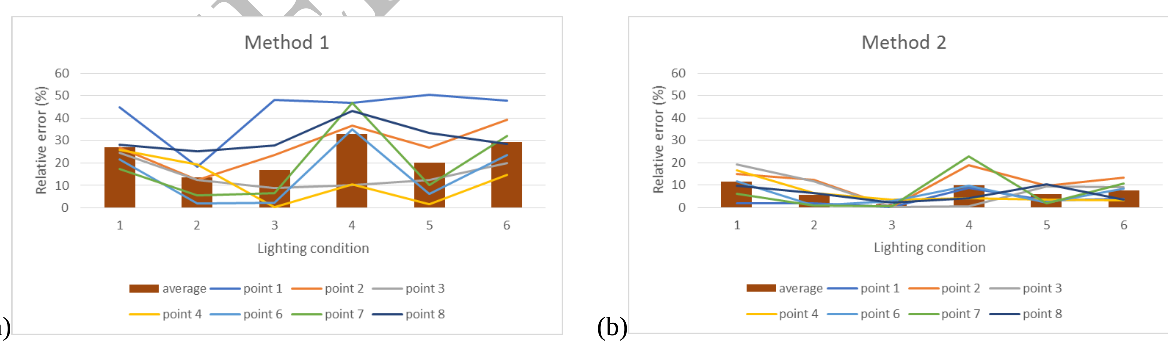

Fig. 3. (a) Illuminance average relative error using Method 1; (b) Illuminance average relative error using Method 2.

In Experiment 1, point 5 is used as the calibration point and not used for calculating the relative error. For Method 2, to obtain luminance and illuminance values from the HDRI, Table 3 and Table 4 in Appendix shows the R^2 ranges from 0.9869 to 0.9986 and from 0.9796 to 0.9993, respectively. The average relative error of luminance measurements compared to measurements using a luminance meter for Method 1 and Method 2 ranges from 7.19% to 23.06% and from 4.54% to 39.25%, respectively. The maximum relative error of Method 1 is 31.91%, recorded on point 4 in lighting condition 4 while for Method 2 it is 54.7%, recorded on point 8 in lighting condition 1 (Fig. 2). The average relative error of illuminance measurements compared to measurements using the illuminance meter for Method 1 and Method 2 ranges from 13.61% to 32.83% and from 1.42% to 11.54%, respectively. The maximum relative error of Method 1 is 50.43%, recorded on point 1 in lighting condition 5 while for Method 2 it is 22.74%, recorded on point 7 in lighting condition 4 (Fig. 3).

3.2. Experiment 2 measurement results

The calibration point used in Experiment 2 is point 6. In luminance measurement using Method 2, point 5 is eliminated and not used because the R^2 is 0.6454, whereas for the other points R^2 ranges from 0.9284 to 0.9891. In the illuminance measurement using Method 2, all points are used including point 5 as the R^2 ranges from 0.9248 to 0.9979 (Table 5 and Table 6 in Appendix). The average relative error of luminance measurements for Method 1 and Method 2 ranges from 5.39% to 11.87% and from 6.16% to 13.61%, respectively. The maximum relative error of Method 1 is 31.2%, recorded on point 4 in lighting condition 2 while for Method 2 it is 21.12%, recorded on point 2 in lighting condition 1 (Fig. 4). The average relative error of illuminance measurements for Method 1 and Method 2 ranges from 5.78% to 11.85% and from 2.59% to 11.96%, respectively. The maximum relative error of Method 1 is 25.41%, recorded on point 4 in lighting condition 2 while for Method 2 it is 21.85%, recorded on point 3 in lighting condition 1 (Fig. 5).

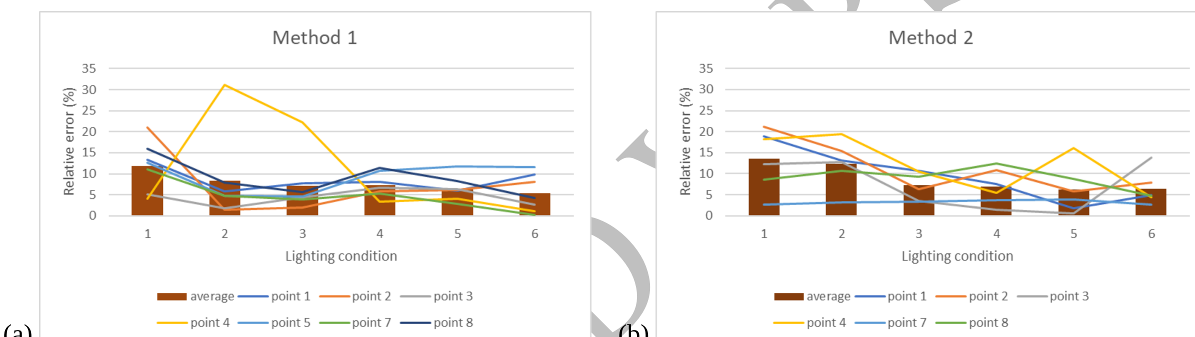

Fig. 4. Luminance average relative error using Method 1; (b) Luminance average relative error using Method 2.

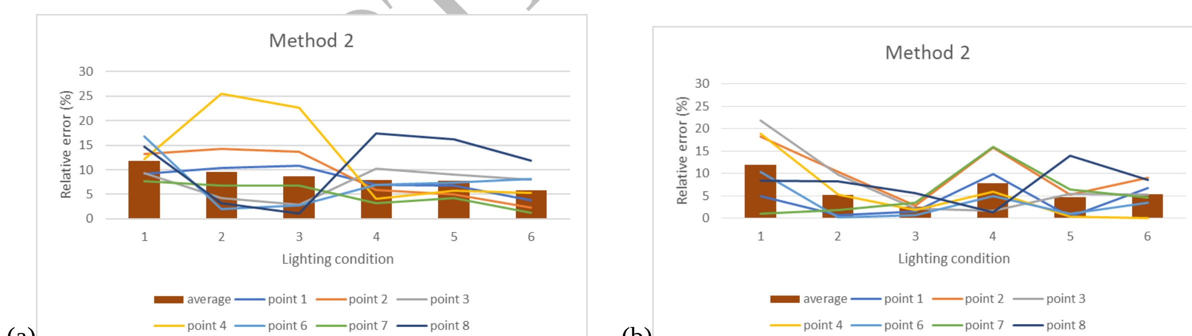

Fig. 5. (a) Illuminance average relative error using Method 1; (b) Illuminance average relative error using Method 2.

3.3. Paired comparison analysis

A paired comparison test [14] was used to observe any significant difference between the luminance and illuminance measurement values obtained by the IP cam experiment using Method 1 and Method 2 compared to values obtained using luminance and illuminance meters. Table 1 shows the t-test value of the luminance and illuminance results. With n = 42, the t-critical value for a two-tailed test with α = 0.05 is 2.019, except for the luminance measurement in Experiment 2 using Method 2, which only has n = 36, so the t-critical value is 2.030. Both Experiment 1 and Experiment 2 results indicate that luminance measurements using Method 2 prove that the two groups are significantly different as the t-test value is higher than the t-critical value. Conversely, Method 2 proves that the two groups of illuminance measurement are comparable, whereas measurements using Method 1 indicate a significant difference between HDRI generated by IP cam and illuminance measurement results.

Table 1. t-test values of luminance and illuminance for HDRI and measurement devices

Measured	Method	Experiment 1 t-test value	Experiment 2 t-test value
Luminance	1	0.249	1.683
Luminance	2	4.917*	4.626*
Illuminance	1	5.576*	2.035*
Illuminance	2	1.144	0.875

*t-test value higher than t-critical value

4. Discussion and conclusion

Paired analysis indicates that luminance measurements using Method 1 and illuminance measurements using Method 2 are comparable. Table 2 shows the average relative error of luminance measurements using Method 1 and illuminance measurements using Method 2. The average relative error of luminance and illuminance measurement ranges from 5.39% to 23.06% and from 1.42% to 1.96%, respectively, which is still acceptable for an HDRI measurement device with accuracy ranging from 5% to 27% [15, 16]. Although the luminance measurement maximum error recorded in Measurement 1/Method 1 is higher than 30%, the average relative error is still acceptable and there is no significant difference between HDRI and the measurement devices.

Table 2. Average relative error between HDRI and measurement devices

Measured	Average relative error
Luminance (using Method 1)	7.19%–23.06% (Experiment 1) ; 5.39%–11.87% (Experiment 2)
Illuminance (using Method 2)	1.42%–11.54% (Experiment 1) ; 2.59%–11.96% (Experiment 2

The results indicate that a commercial IP camera can be used as a view sensor although there is some limitation related to accuracy. To obtain luminance values from HDRI, Method 1 (calibration method) is more accurate compared to Method 2 (equation method).

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Appendix

Table 3. Luminance equation in Experiment 1

Point	Luminance equation	R^2
1	$L_{HDRI} = 1.2371 * L_{pixel} + 0.392$	0.993
2	$L_{HDRI} = 1.2579 * L_{pixel} - 7.225$	0.9872
3	$L_{HDRI} = 0.8704 * L_{pixel} + 1.747$	0.9986
4	$L_{HDRI} = 0.732 * L_{pixel} + 13.192$	0.9889
6	$L_{HDRI} = 0.8446 * L_{pixel} + 9.1789$	0.9869
7	$L_{HDRI} = 0.9555 * L_{pixel} + 2.7841$	0.9975
8	$L_{HDRI} = 1.0839 * L_{pixel} + 0.8673$	0.9982

Table 4. Illuminance equation in Experiment 1

Point	Illuminance equation	R^2
1	$E_{HDRI} = 1.6894 * L_{pixel} - 10.064$	0.9947
2	$E_{HDRI} = 1.321 * L_{pixel} - 34.071$	0.9854
3	$E_{HDRI} = 0.9571 * L_{pixel} + 23.025$	0.9993
4	$E_{HDRI} = 0.7466 * L_{pixel} + 83.383$	0.9882
6	$E_{HDRI} = 0.8422 * L_{pixel} + 58.406$	0.9796
7	$E_{HDRI} = 0.9363 * L_{pixel} + 24.595$	0.9977
8	$E_{HDRI} = 1.2465 * L_{pixel} - 4.4417$	0.9963

Table 5. Luminance equation in Experiment 2

Point	Luminance equation	R^2
1	$L_{HDRI} = 0.8943 * L_{pixel} + 10.957$	0.9492
2	$L_{HDRI} = 0.8268 * L_{pixel} + 12.36$	0.9284
3	$L_{HDRI} = 0.9675 * L_{pixel} + 2.6588$	0.987
4	$L_{HDRI} = 1.0183 * L_{pixel} – 3.5353$	0.9891
5	$L_{HDRI} = 12.857 * L_{pixel} – 657.19$	0.6452
7	$L_{HDRI} = 0.951 * L_{pixel} + 2.9745$	0.9823
8	$L_{HDRI} = 0.9023 * L_{pixel} + 5.4608$	0.9334

Table 6. Illuminance equation in Experiment 2

Point	Illuminance equation	R^2
1	$E_{HDRI} = 0.9444 * L_{pixel} + 20.891$	0.9935
2	$E_{HDRI} = 0.9119 * L_{pixel} + 27.318$	0.9843
3	$E_{HDRI} = 1.1515 * L_{pixel} + 2.1$	0.9968
4	$E_{HDRI} = 1.2423 * L_{pixel} – 29.053$	0.9958
5	$E_{HDRI} = 1.1673 * L_{pixel} – 3.0699$	0.9979
7	$E_{HDRI} = 1.0301 * L_{pixel} + 2.1462$	0.9899
8	$E_{HDRI} = 0.9304* L_{pixel} + 53.738$	0.9248

References

[1] M.N. Inanici. Evaluation of high dynamic range photography as a luminance data acquisition system. *Light Res Technol.* 2006;38(2):123-136. doi:10.1191/1365782806li164oa

[2] A. Guha, A. Nyboer, D.K.Tiller. A Review of Illuminance Mapping Practices from HDR Images and Suggestions for Exterior Measurements. *LEUKOS - J Illum Eng Soc North Am.* 2022;Published online 26 Jul 2022:1-11. doi:10.1080/15502724.2022.2091590

[3] J. Mardaljevic, S. Cannon-Brookes, N. Blades, K. Lithgow. Reconstruction of cumulative daylight illumination fields from high dynamic range imaging: Theory, deployment and in-situ validation. *Light Res Technol.* 2021;53(4):311-331. doi:10.1177/1477153520945755

[4] V. Kumaragurubaran, M. Inanici. Hdrscope: High dynamic range image processing toolkit for lighting simulations and analysis. *Proc BS 2013 13th Conf Int Build Perform Simul Assoc.* 2013;(February):3400-3407.

[5] C. Pierson, C. Cauwerts, M. Bodart, J. Wienold. Tutorial: Luminance Maps for Daylighting Studies from High Dynamic Range Photography. *LEUKOS - J Illum Eng Soc North Am.* 2021;17(2):140-169. doi:10.1080/15502724.2019.1684319

[6] P.E. Debevec, J. Malik. Recovering high dynamic range radiance maps from photographs. *In: SIGGRAPH '97: Proceedings of the 24th Annual Conference on Computer Graphics and Interactive Techniques*. ; 1997:369–378. doi:10.1021/jo01029a072

[7] A. Motamed, L. Deschamps, J.L. Scartezzini. Eight-month experimental study of energy impact of integrated control of sun shading and lighting system based on HDR vision sensor. *Energy Build.* 2019;203:1-22. doi:10.1016/j.enbuild.2019.109443

[8] M. Kim, I. Konstantzos, A. Tzempelikos. Real-time daylight glare control using a low-cost, window-mounted HDRI sensor. *Build Environ.* 2020;177(January):106912. doi:10.1016/j.buildenv.2020.106912

[9] J. Xiong, A. Tzempelikos. Model-based shading and lighting controls considering visual comfort and energy use. *Sol Energy.* 2016;134:416-428. doi:10.1016/j.solener.2016.04.026

[10] O.A. Olamide, Y.N. Asafe, O.I. Olawale, A.O. Akinleye. Networking CCTV Cameras & Passive Infra-Red Sensors for E-classroom Monitoring System : Proactive Approach to Quality Assurance in Education System. *Int J Adv Netw Appl.* 2017;8(5):3213-3219.

[11] F.O. Okorodudu. Moving towards motion activated security camera system with live feed and call routing. *Niger J Sci Environ.* 2021;19(1).

[12] C. Carrillo, E. Diaz-Dorado, J. Cidrás, et al. Lighting control system based on digital camera for energy saving in shop windows. *Energy Build.* 2013;59:143-151. doi:10.1016/j.enbuild.2012.12.012

[13] R. Compagnon. Radiance: a simulation tool for daylighting systems. Published 1997. Accessed December10, 2021. http://radsite.lbl.gov/radiance/refer/rc97tut.pdf

[14] Z. Kong, M. Utzinger, L. Liu. Solving glare problems in architecture through integration of hdr image technique and modeling with diva. *14th Int Conf IBPSA - Build Simul 2015, BS 2015, Conf Proc.* 2015;(December 2015):1213-1220. doi:10.26868/25222708.2015.2429

[15] T. Kruisselbrink, M. Aries, A. Rosemann. A Practical Device for Measuring the Luminance Distribution. *Int J Sustain Light.* 2017;36:75-90. doi:10.26607/ijsl.v19i1.76

[16] V. Zaikina, B.S. Matusiak. Verification of the Accuracy of the Luminance-Based Metrics of Contour, Shape, and Detail Distinctness of 3D Object in Simulated Daylit Scene by Numerical Comparison with Photographed HDR Images. *LEUKOS - J Illum Eng Soc North Am.* 2017;13(3):177-188. doi:10.1080/15502724.2016.1219269

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