Influence of spectral properties of light sources on perceived and recorded images

Jacek Kusznier

Faculty of Electrical Engineering, Białystok University of Technology, Wiejska 45D, 15-351 Białystok

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Abstract—The text presents differences between the mechanism of seeing and recording images and potential sources of errors in color reproduction in recorded images. The measurements show that despite the relatively high values of indices (R_e, R_i, R_o) not all tested lamps are suitable for use on a photo set, as indicated by the value of TLCI index. The lighting requirements on a film set prioritize the quality of color reproduction, even at the expense of reducing the Luminous efficacy of a source (LES) value.

Quality requirements for lighting of a shooting set are significantly different from those for general illumination. This is due to a different mechanism of image recording with devices based on array detectors rather than the human visual sense. There are a total of five types of photoreceptors on the retina. Four of these are responsible for eliciting visual sensations. Each of the photoreceptor types is distinguished by different spectral sensitivity characteristics (Fig. 1). [1–3] The radiation has a different effect on different organisms and on man-made detectors. [4–6]

The maximum luminous efficacy of radiation (LER) in photopic vision is 683 lm/W and is achieved at a wavelength of 555 nm.

\[
\text{LER} = \frac{683 \text{ lm}}{W} \int \frac{V(\lambda)P_{\text{opt}}(\lambda) d\lambda}{\int P_{\text{opt}}(\lambda) d\lambda}
\]  

Striving to achieve the highest possible LER value leads light source manufacturers to narrow the light spectrum emitted by the sources. This is because the radiation at the edge of the visible spectrum, both in the violet and blue color range as well as in the red, is characterized by low LER values. Reducing the white light spectrum from 380–780 nm to 400–700 nm covers 99.93% of the optical energy below spectral luminous efficiency function for photopic vision. However, limiting the spectral width results in lower values of the color rendering index. However, in order to ensure that colors can be reproduced correctly, it is necessary to use sources whose emission covers the entire visible range as far as possible.

The LER of white light sources can therefore reach a maximum value of 520 lm/W. The lines of the maximum LER values in the CIE 1931 diagram are shown in Fig. 2. [14–18]

The luminous efficacy of a source (LES) will always be less than the LER since only part of the electrical power is converted into radiation.
The mechanism of recording images with array detectors is to reproduce, as far as possible, the impressions that we perceive with our sense of sight in the process of daytime vision. Semiconductor detectors currently used in image recording technology are based on silicon (Si), whose spectral sensitivity is different from \( V(\lambda) \) and additionally extends beyond the visible range (Fig. 1).

To enable human-like color reproduction, a grid of color filters is applied to the array detector, resulting in the individual pixels of the array recording a signal only within a narrow range of the selected color. The most commonly used is the RGB color system. Another technique that allows to record color images is the use of three arrays. In this case, each sensor receives light of a different primary color (RGB) that is split by an optical system.

In addition, all pixels on an array detector are distributed evenly across its surface, which is also different from the distribution of photoreceptors on the retina. The dissimilarity between the human sense of sight and the array detector led to the need to define a new index. The standard observer’s model created by CIE is not suitable for modern recording devices and set lighting. [19] As a result, the color rendering indexes defined for lighting did not allow the evaluation of light sources in set lighting and television production in a meaningful way. This resulted in the need for costly and time-consuming color corrections in the recorded images. The previously used color rendering indexes proved to be insufficient in the case of LED and fluorescent sources.

A StellarNet Blue-Wave UVIS-50 spectrometer was used for the measurements. The results were calculated in a calculation sheet and in the ColorCalculator v. 7.77 program.

![Fig. 2. Contours of maximum possible luminous efficiency of radiation shown on CIE 1931 chromaticity diagram (adapted from MacAdam 1950, Schelle 2014).](image)

![Fig. 3. Spectral luminous efficiency in photopic vision and TLCI-2012 Camera with adjusted Matrix (developed on the basis of [21-23]).](image)

![Fig. 4. Spectral power distribution of the measured lamps.](image)
The measurements show that despite the relatively high values of indices ($R_a$, $R_9$ and $R_g$) not all tested lamps are suitable for use on a photo set, as indicated by the value of TLCI index.

The lighting requirements on a film set prioritize the quality of color reproduction, even at the expense of reducing the luminous efficacy of a source (LES) value. The standard camera model and TLCI-2012 index had to be created due to the non-human white balance mechanism in cameras. The use of array detectors in digital devices versus classical basic silver halide photosensitive materials created problems mainly in the near infrared (750–1100 nm). Radiation at these wavelengths is used in consumer devices to increase apparent sensitivity in low light conditions. However, this is at the expense of degraded color reproduction. This is because LED sources have different levels of IR radiation compared to tungsten lighting. Color reproduction errors in lower cost devices are due to poor filtering of radiation, particularly in the IR range.

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References

[1] L. T. Sharpe, A. Jagla, W. Jagle, J. Vision 5(11), 948 (2012).
[2] K. Mangold, J. A. Shaw, M. Vollmer, Eur. J. Phys. 34, 51 (2013).
[3] M. P. Simunovic, Arch. Ophthalmol. 130(7), 919 (2012).
[4] M. Gilewski, Phot. Lett. Poland 11(3), 87 (2019).
[5] M. Gilewski, Phot. Lett. Poland 11(4), 115 (2019).
[6] I. Fryc, E. Czech, Opt. Eng. 41(10), 2402 (2002), https://doi.org/10.1117/1.1503344.
[7] L. Bellia, U. Blaszcak, F. Fragliasso, L. Gryko, Solar Energy 208, 830 (2020).
[8] J. Kusznier, W. Wojtkowski, Impact of climatic conditions on PV panels operation in a photovoltaic power plant, IEEE 15th Selected Issues of Electrical Engineering and Electronics (WZEE), Zakopane, Poland (2019).
[9] J. Kusznier, W. Wojtkowski, Impact of climatic conditions and solar exposure on the aging of PV panels, IEEE 15th Selected Issues of Electrical Engineering and Electronics (WZEE), Zakopane, Poland (2019).
[10] J. Fan, Y. Li, I. Fryc, C. Qian, X. Fan, G. Zhang, IEEE Photon. J. 12(1), 1 (2020); Art no. 8200218.
[11] M. Gilewski, L. Gryko, A. Zajac, Proc. SPIE 8902, 89021D (2013).
[12] J. Kusznier, W. Wojtkowski, Phot. Lett. Poland 12(1), 16 (2020).
[13] J. Kusznier, Changes in the Spectral Power Distribution of Light Sources for Smart Lighting, IEEE 14th WZEE (2018).
[14] H.F. Ivey, J. Opt. Soc. Am. 53, 1185 (1963).
[15] F. Zhang, H. Xu, Z. Wang, Appl. Opt. 56, 1962 (2017).
[16] T.W. Murphy Jr. J. Appl. Phys. 111, 104909 (2012), https://doi.org/10.1063/1.4721897.
[17] P.-C. Hung, J.Y. Tsao, J. Display Technol. 9, 405 (2013).
[18] V.M. Lisitsyn, V.S. Lukash, S.A. Stepanov, Yu Yangyang, AIP Conf. Proc. 1698, 060008 (2016); doi:10.1063/1.4937863.
[19] J. Kowalska, I. Fryc, Przeglad Elektrotechniczny R. 95(7), 94 (2019).
[20] I. Fryc, I. Fryc, A. Wasowski, Przegląd Elektrotechniczny R. 92(2), 218 (2016); doi: 10.15199/48.2016.02.55
[21] TECH 3353, Development of a “standard” television camera model implemented in the TLCI-2012, Source: FTV-LED, EBU, Geneva November 2012
[22] TECH 3354, Comparison of CIE colour metrics for use in the television lighting consistency index (TLCI-2012), Source: FTV-LED, EBU, Geneva November 2012
[23] TECH 3355, Method for the assessment of the colorimetric properties of luminaires the television lighting consistency index (TLCI-2012) and the television luminaires matching factor (TLMF-2013), Source: FTV-LED Geneva March 2017
[24] J. Kusznier, Przegląd Elektrotechniczny R. 84(8), 182 (2008).

Tab. 1. Measured index values of selected lamps (based on own research)

| Lamps                | CCT [K] | $R_a$ | $R_9$ | $R_{12}$ | $R_{T}$ | $R_g$ | $TLCI$ |
|----------------------|---------|-------|-------|----------|---------|-------|--------|
| Macro LED Ring Flash | 6089    | 95    | 85    | 71       | 92      | 99    | 97     |
| Fluorescent foto light | 6050   | 87    | 66    | 73       | 85      | 103   | 72     |
| Halogen classic Philips 4W | 3107 | 99    | 96    | 98       | 99      | 100   | 100    |
| LED Superstar classic A/0 Osram | 4153 | 86    | 17    | 66       | 85      | 91    | 75     |
| Dulux stick Osram 20W | 2830 | 83    | 10    | 51       | 75      | 104   | 47     |