A Spectral Database of Commonly Used Cine Lighting

Andreas Karge; Stuttgart Media University; Stuttgart, Germany
Jan Fröhlich; Stuttgart Media University; Stuttgart, Germany
Bernd Eberhardt; Stuttgart Media University; Stuttgart, Germany

Abstract

In recent years, multiple methods have been published that describe how to estimate the spectral response of a camera system or object reflectance spectrum. These methods are becoming increasingly important for the color processing pipeline in movie productions. Knowing the spectral power distribution of light sources used in a movie production is essential for a spectral based approach to ensure a correct color reproduction in movie data creation. We present a thoroughly documented data set of spectral power distributions of typical film and TV lighting. The data set can be used to create more precise camera characterizations and help to develop spectral color processing pipelines. Furthermore, the spectral power distribution data set can be employed to detect and validate over-aged or damaged lighting, by comparing their spectra to our reference measurement.

Motivation

In imaging systems the genesis of image data can be described by radiometric and optical parameters. The resulting image data is a linear combination of light sources illuminating an object in the scene which is then registered by a camera system through a lens onto the image plane and is finally post-processed electronically. The camera system response consists of the spectral transmission of the lens, the sensors spectral response and the electro-optical transfer curve. Therefore, the overall parameter set for image formation consists of the spectral power distributions (SPD) of lighting, the object's spectral reflectance and the spectral response of the whole camera system.

In consequence this means, if the SPD of illumination and one other parameter is given, the third parameter can be estimated. In movie production, it is common to use camera systems with different spectral responses even for images that are afterwards cut together in a single sequence. This leads to color differences which can be avoided if we estimate the camera systems spectral responses. One standardized method to ensure color consistency between different cameras is the Academy Color Encoding System (ACES) which has been defined by the Academy of Motion Picture Arts and Sciences (AMPAS). According to this framework every camera system should be described through a digital camera input device transformation (IDT) [1]. The creation for such an IDT requires the known SPD of the used cine lighting.

Other important benefits from the use of spectral lighting data in cine movie production are evident. SPDs of the same lighting type can be compared to detect deviations caused by maladjustments and ageing or to evaluate color differences, if one lighting type is replaced by another. A given lighting SPD can be used as a reference white point and even a linear combination of such SPDs might be used to simulate the effect of mixed lighting at a location. Furthermore, our measurements are fundamental for building up ageing statistics and the matching of unknown lighting.

Currently, there is no public accessible database with SPDs of commonly used lighting systems available. Neither producers of cine lighting technology such as ARRI, Kino Flo [2] or Dedolight nor producers of non-cine lighting and lighting bulbs such as General Electric [3], Philips or Osram [4] publish the numerical data of SPDs, with the exception of a few graphs.

Having said that, two public databases containing numerical data should be mentioned. One consists of a collection of lights and bulbs commonly used in galleries [5]. The other one contains data taken from a small number of street lights and headlights for trucks [6]. In most cases we could not find measurement descriptions, neither the setup procedure nor the geometry.

The need of such a numerical spectral database of commonly used cine lighting, and having a representative set of cine lighting at Stuttgart Media University (HdM) motivated us to create the data set presented in this work. The data set includes SPDs of lights based on common light emitting principles. These are Tungsten, fluorescence and metal halid gas discharge lighting. Furthermore, it contains upcoming light-emitting diode based semiconductor light sources.

Methods

To measure SPDs in a standardized and reproducible manner, an appropriate method must be chosen from existing standards. A commonly used method by producers of lighting technology is a measurement geometry setup with an integrating sphere. It is specified by the International Commission On Illumination (CIE) as an 8° geometry [7], with the light source being positioned at the sphere's light entry port and a spectrometer that measures the spectral irradiance at the sphere's exit port. Using this method for cine lighting has some drawbacks in practice, since lighting exit ports can be large with up to one meter or more and the sphere's entry must be of the same dimension. Therefore one measurement condition for this method can be hardly fulfilled: the sum of areas of entrance and exit ports must be less than 5 % of the whole sphere's area. This leads to a very huge sphere, which is not applicable. Furthermore, the whole radiance (including light coming from the edge of the lighting's exit port) is integrated. Hence, the colored fitting and the casing of the lamp might reflect some light. In consequence, this setup does not represent a typical setup of object illumination in movie production, where the object normally only reflects a small solid angle of the light cone.

Another measurement method for lighting is proposed in [8]. The lighting source illuminates a white reflecting surface whose spectral power distribution is measured. Using an ideal diffuser, i.e. a Lambert radiator for this surface and knowing the relative spectral reflectance of this white surface allows calculating the SPD of the illumination source for a given geometry. This geometry might define the positions of illuminant, white target and measuring device. ISO standard 3664:2000 [9] describes a standardized geometry for this measurement setup, the 45°/0° geometry.

For the presented database the 45°/0° geometry was chosen, because this geometry is a good approximation for the widely used 45 degree portrait lighting setup used in photography and movie production. Additionally, this geometry has the advantage that only a small solid angle of the lighting cone reflected by the object is measured which is an adequate representation of the real scene.

Measurement Setup

The realization of the chosen 45°/0° geometry requires some additional elements to ensure a reproducible and fast setup. Figure 1 shows the measurement setup used for acquiring the SPDs of the presented database. Additional elements are a camera and a ceiling mounted cross target, a removable and height/width adjustable arm, a table with a height adjustable platform, on which the spectrometer is mounted, and a diffuser. Diffuser and white target are exchangeable positioned on an x/y table. The geometric parameters are defined as follows:

- ***a*** vertical distance from the white patch surface to the front of the spectrometer lens.
- ***b*** horizontal distance from the optical axis spectrometer to the center of the maximum vertical illumination aperture.
- ***r*** distance from the white patch surface to the corner edge point of the lighting exit port.
- α angle between optical axis of spectrometer and the surface normal at the center of light source aperture.
- β angle between the plane defined by the edge points of light source exit port and the horizontal plane.

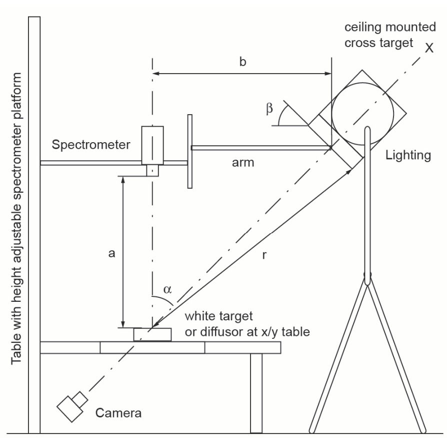

Figure 1. *Measurement setup*

Using a 45°/0° geometry means that α=45° with ***a*** pointing upwards along the optical axis of the spectrometer. In our case the horizontal distance ***b*** is variable in a range of 1 to 2.5 m and depends on the radiation power of the light being measured and the dynamic range of the spectrometer. For a fast setup of ***b,*** a horizontally pivotable arm is used. This arm is adjustable in width and height. The right arm end is forming a cone and ends at the ideal 45° tilted axis. Parameter ***r*** is a function of ***a***, ***b***, α and the geometric properties of the respective exit port of the considered light, which can be rectangular or circular shaped. If we measure a set of ***r***, e.g. the 4 corner points r_{r1}-r_{r4} of a rectangular shape or three points r_{c1}-r_{c3} on the perimeter for a circular shape (figure 2), we can also estimate β.

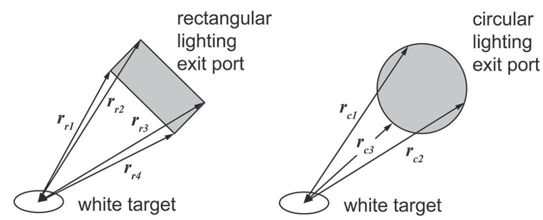

Figure 2. *Measured distances for different shaped lighting exit ports*

Ideally, β should be equal to α, but in practice this is sometimes not the case. In order to reproduce α in a standardized manner, a cross target is placed at the measurement laboratory's ceiling where it is intersected by a straight line with 45° upward slope having its origin at the center of the horizontally placed white reflection target. This cross target (notch) and the tapered end of the arm (bead) forms a notch and bead sighter device, which is observed by a camera. The camera is used to visually aim at the cross in the center of the picture and is placed under the removable reflection target. Hence, the optical axis of the camera is manually adjusted to the straight line pointing from the center of the reflection target to the center of the light to be measured. In addition, the right cone end of the arm also should be shown in the center by the camera during the setup process. In order to avoid stray light that directly illuminates the spectrometers lens, it was also ensured that ***b***>***a***.

The white target we used is made of polytetrafluoroethylene (Zenith-Polymer by SphereOptics) and the employed spectrometer is a PhotoResearch PR 650, which can measure the radiance (W/(sr m^2 nm)) in a cone around the optical axis within an angle of 1°. For our white target's diameter of 5 cm and 1° viewing angle, a chosen ***a***=1m is suitable. Test measurements showed that an integration time of at least 500 ms is required to minimize errors by variation of the spectrometer's shutter open/close cycle according to short time stability of the device and main power frequency of 50 Hz.

All measurements have been performed 15-30 min after the lighting was switched on. The room was air-conditioned, with a temperature of 23°C and approximately 30% relative humidity. The measured SPDs have been post processed in order to correct the white patch spectral reflectance. Every SPD of the database is an average of 100 single measurements captured during a period of at most 5 minutes.

Measurement Process

The measurement process consists of 3 steps: the setup of correct positions for the spectrometer, white target and lighting. While the first and second step can be initially done at once, the adjustment of the lighting is much more difficult and must take the different lighting exit port shapes into account.

The setup of the 45°/0° geometry starts with the horizontal alignment of the white patch. Subsequently, a horizontal aligned mirror replaces the patch. The mounted spectrometer is tilted so that the viewfinder shows the spectrometer's lens centered (principle of autocollimation). Replacing the mirror with the target, the x/y table is then shifted to view the target centered in the viewfinder. Distance $\boldsymbol{a}$ can be adjusted now. In the second step, this target is removed temporarily and the camera is adjusted in such a way, that the white target's center and the ceiling mounted cross target are congruent and projected in the center of the image plane. After that, the vertical arm is adjusted in height for a given $\boldsymbol{b}$ in a way, that the cone end of the arm is also shown congruent in the center of the image. From this moment on the setup is taken as constant for all following lighting measurements.

Finally, the geometrical setup sequence of the lighting is done. For this third step, it must be kept in mind, that the light cone, which exits the light source exit port is not an ideal Gaussian beam with a transversal decreasing intensity. This is due to the different light forming elements used in the lights. For example, some cine lights use Fresnel lenses and reflecting diffusers, in order to realize several "spot" or "flood" illumination characteristics. For multiple light sources, especially ARRI+ and ARRI Daylight series, we found one local minimum of light intensity near the optical axis embedded by two maxima. This effect occurred in particular for variable reflectors which use the "flood" reflector arrangement. For some lamps, the global maxima is not centered at the optical axis, but slightly displaced.

Our procedure takes into account that the cine lighting operator typically tilts the lighting source visually, in a way that the maximum intensity is centered at the object of interest. This means, that β slightly differs from the ideal value of α=45°. Considering these facts, we defined and use the lighting setup and measure process as follows:

- vertically tilt the lamp's exit port by approx. 45° (LS0)
- position lighting exit port center at the tapered end of the arm and remove arm by 90° horizontally pivoting (LS1)
- switch lighting on and wait 15 min to avoid temporally transient phenomena (LS2)
- tilt lighting vertically and horizontally until the white target visually appears with maximum intensity to the human observer (LS3)
- position diffusion disc in front of camera (LS4)
- continuously tilt lighting horizontally starting by 45° to -45° and back to find the global maximum/maxima given by columns histogram of camera image (LS5)
- if a local minimum is found between two maxima or one global maximum, center this minimum/maximum in camera's image by tilting the light in the plane (as in the previous step LS5 respectively LS7) and observe the columns histogram of the camera image (LS6)
- continuously tilt lighting vertically starting by 45° to -45°and back to find the global maximum/maxima given by columns histogram of camera image (LS7), do LS6
- remove diffuser (LS8)
- verify position of center of lighting exit port relating to image plane center, i.e. the cross target position (LS9)

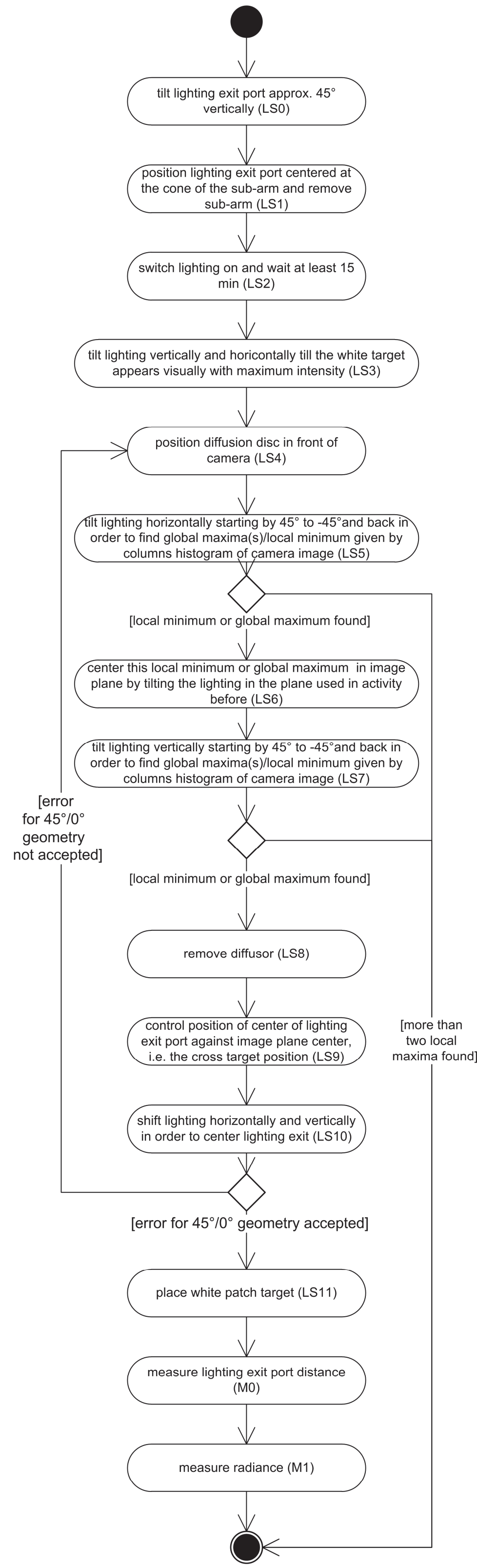

Figure 3. *Lighting setup process and measurement activities*

- shift lighting horizontally and vertically in order to center lighting exit port (LS10)
- do steps LS4-LS10 n-times iteratively in order to decrease error for α as expected to 45°
- place white patch target (LS11)
- measure distances r_{c1}-r_{c3} respectively r_{r1}-r_{r4} (M0)
- measure the SPD of the lighting (M1)

Figure 3 shows the activity diagram for this lighting setup sequence. It additionally shows the possible stops, if more than two maxima were found, which indicates a damaged or maladjusted lighting.

Results

For our database, we have measured available lights that represent the three widely used artificial light emitting principles. These are Tungsten based (TU), fluorescence (FL) and metal halid gas discharge (HMI) lighting. Furthermore upcoming light-emitting diode based semiconductor light sources (LED) were measured. Several lighting can be used in "spot" or "flood" mode, by shifting a Fresnel lens in front of the lighting. Others are equipped with removable diffusors and yet others have variable power supplies.

In the following, we will present samples of measured SPDs alongside with relevant colorimetric data such as the correlated color temperature (CCT), the color rendering index (CRI) and the chromaticity **u'v'** coordinates of the CIE 1976 uniform color scale (UCS) system using the 2° standard observer. A comparison of radiances related to ideal black body radiators or standard D illuminants are shown as well as deviations for **u'v'** derived from the specified CCT values of the manufacturer.

Figure 4 shows samples for spectral radiances of Tungsten, fluorescent and HMI cine lighting. The range of radiances contains 3 ranges of magnitude in power from low power fluorescence lighting (Bron Kobold Lumax KF 55), to medium power Tungsten

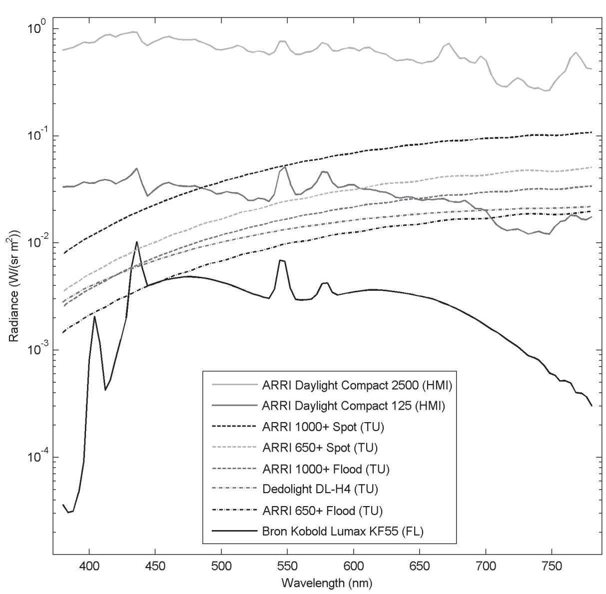

***Figure 4.** Random SPD samples for different lighting types*

(ARRI 650/1000+ and Dedolight DL-H4) and HMI lighting (ARRI Daylight Compact 650), and up to high power HMI lighting (ARRI Daylight Compact 2500). For ARRI 650/1000+, the variation for the Fresnel lens exit port at positions for spot and flood is shown (spot/flood).

For Tungsten lighting, figure 5 shows two ARRI 650+ spectral radiances, in which one light L1 is well adjusted (L1 Flood, L1 Spot) and the other one L2 is maladjusted (L2 Flood, L2 Spot). Figure 6 shows the normalized radiance and CRI of one ARRI 1000+ sample at spot position and the ideal black body radiator for the correlated color temperature.

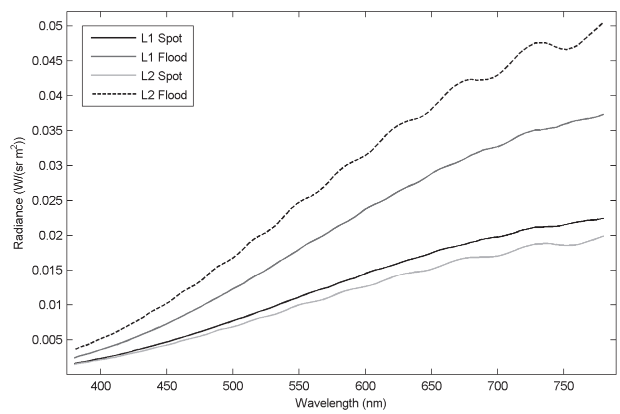

***Figure 5.** ARRI 650+ lighting samples (L1 well adjusted, L2 maladjusted)*

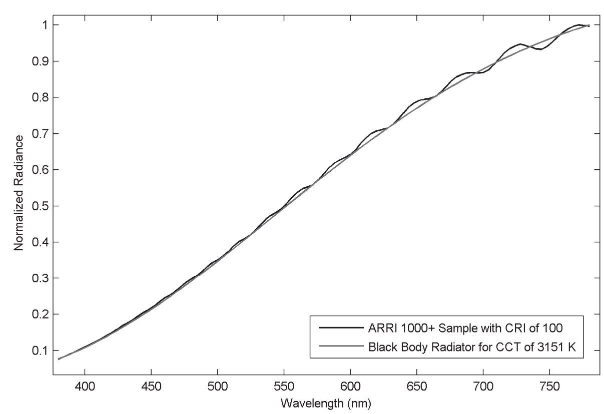

***Figure 6.** ARRI 1000+ sample and black body radiator for CCT*

In order to evaluate the colorimetric deviation and variance, Figure 7 shows the **u' v'** values for the manufacturer specified CCT and a set of Dedolight DL-H4 samples at flood position. The circle has a radius of one just noticeable difference (JND) of **Δc**=0.01 around the **u'v'** coordinates of the manufacturer specified color temperature for this lighting (as for all next **u'v'** figures).

In general, it can be said that for all measured Tungsten based lighting (ARRI 650/1000+ and Dedolight DL-H4 series) the spectral radiance is near the expected radiance for a given black body radiator. All CCT values as well as **u'v'** coordinates turned out to be close to the value specified by the manufacturer. The CRI is close to 100. The ripples in spectral radiance we found are significant in the upper range of visible spectrum and much more distinct for lighting with Fresnel lens exit ports. The reason for that might be subject to future research.

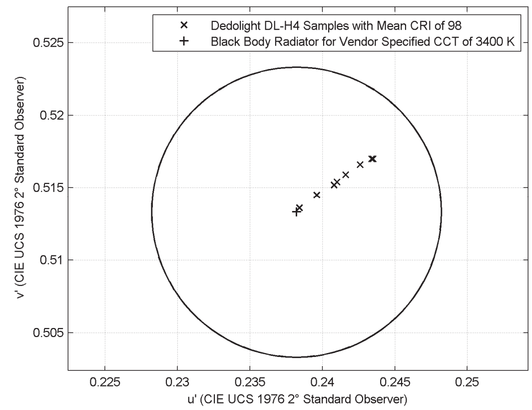

Figure 7. *Chromaticity coordinates for Dedolight DL-H4 samples*

For HMI lighting, Figure 8 shows the spectral radiances of ARRI Daylight Compact lighting, one Compact 2500 sample at light exit port flood position and two Compact 125 samples L1 and L2 at spot/flood position.

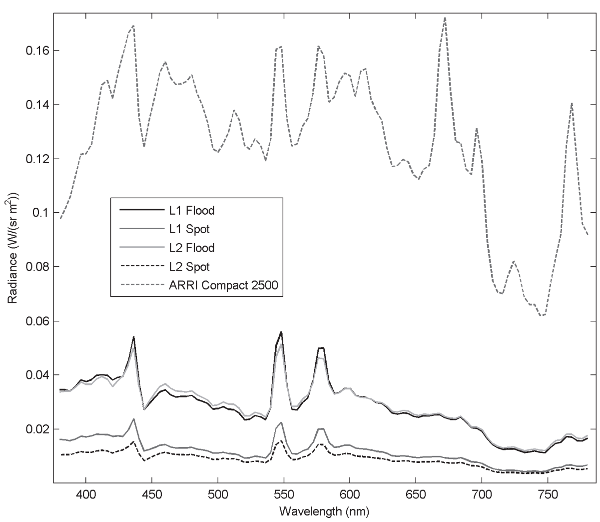

Figure 8. *ARRI Daylight Compact 125 (L1/L2) and Compact 2500 samples*

The **u'v'** coordinates shown in figure 9 are based on the ARRI Compact 125 SPDs of figure 8. They are in general outside of the JND of **Δc**=0.01 of the equivalent standard D illuminant daylight color temperature based values specified by the manufacturer.

For HMI lighting additional SPDs were measured during the power-on phase to evaluate the transient phenomenon. Figure 10 shows the luminance, the CCT, and the **u'v'** coordinates of the first 6.5 minutes after power-on for an ARRI Compact 1200. It shows that already after 4 minutes a stable state for the CCT and **u'v'** is reached.

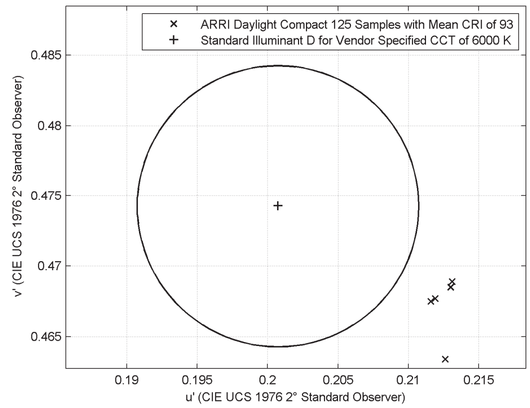

Figure 9. *Chromaticity coordinates of ARRI Daylight Compact 125 samples*

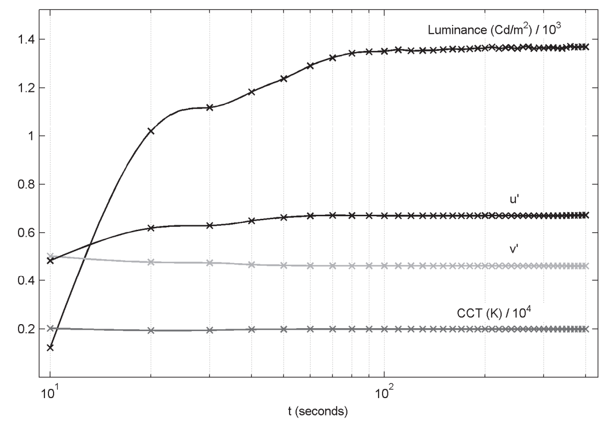

Figure 10. *ARRI Compact 1200 sample showing the time variation of luminance, CCT and chromaticity coordinates after power-on (t=0s)*

For fluorescent lighting, Figure 11 shows normalized SPDs of Bron Kobold Lumax lighting (two samples L1 and L2). The power supply allows two different power steps, min indicates the lower one and max the upper one. In addition to that, an interchangeable reflector can be used. Measurements labeled with + were done with and labeled with – were done without this reflector. Beside the variation of the spectral radiance one might notice, that the SPDs show the fluorescent lines at constant wavelengths, but with different spectral radiances. This variation of radiances is mainly influenced by variance of doping of the tubes' fluorescent layer and the spectral reflectance of the reflector. Like HMI lighting, the UCS coordinates are outside of the reference coordinates for the manufacturer specified color temperature for standard D illuminant daylight. This is mainly influenced by the variation of spectral radiances of distinct lines, for both, HMI and fluorescent lighting.

Figure 12 shows the relative SPD for a Bron Kobold Lumax lighting and the SPD of the standard D illuminant for the manufacturer specified correlated color temperature.

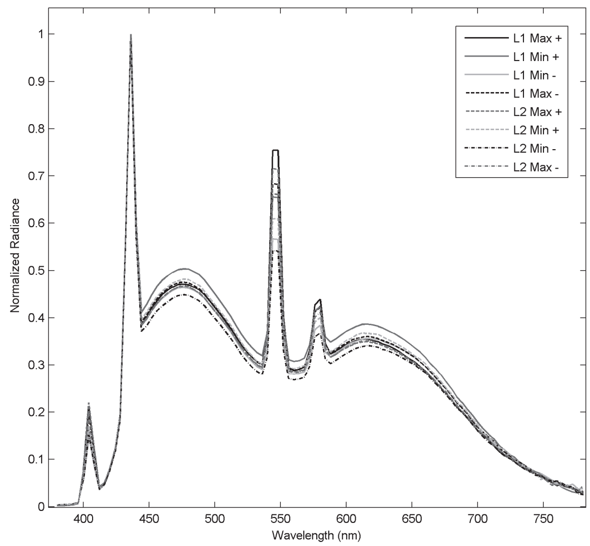

Figure 11. *Bron Kobold Lumax KF 55 samples*

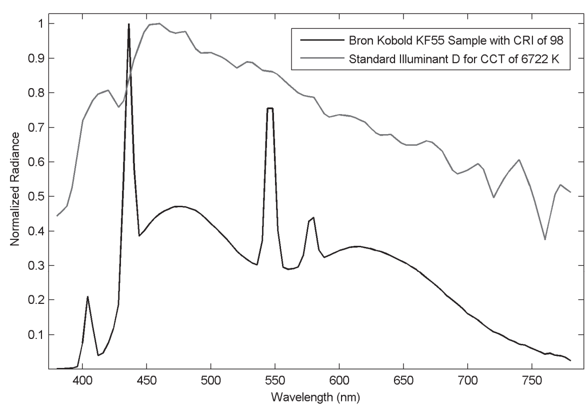

Figure 12. *Bron Kobold Lumax KF55 sample and Standard D Illuminant for correlated color temperature*

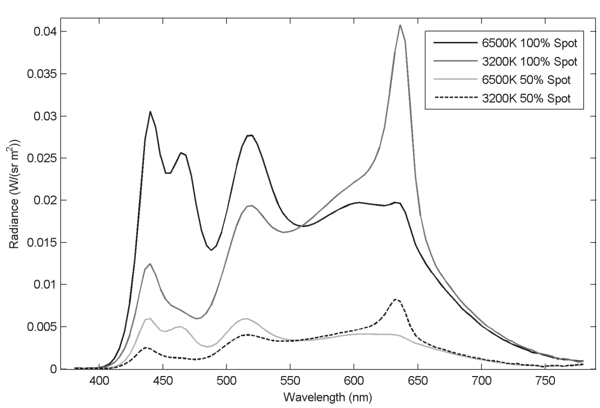

Figure 13. *ARRI L5-C samples for different CCTs*

In contrast to Tungsten, fluorescence and HMI lighting the upcoming LED based lights allow the variation of the CCT in a wide range of CCTs between those of typical Tungsten lighting up to standard D illuminants CCTs. For the data set measurements with a CCT of 3200 K and 6500 K were done. Figure 13 shows an ARRI L5-C sample of a LED based lighting for both CCTs, with 100% and 50% power, and at spot position.

Error Discussion and Limitations

Differences between measured and expected SPDs can be categorized by deviations in geometric and radiometric errors. The ideal 45°/0° observing condition might not be fulfilled because of suggested lighting shift and tilt in measurement setup or maladjusted lighting exit ports. However, the error can be estimated, because for each SPD the r_{c1}-r_{c3}, respectively r_{r1}-r_{r4} are measured.

Radiometric errors are mainly a result by measurement device tolerances, non-ideal reflection by the white target and stray light. Our National Institute of Standard and Technology (NIST) certified spectrometer has a manufacturer specified tolerance of approx. 3% for virtual primaries X, Y and Z. Errors caused by the white patch are deviations from ideal white Lambert diffuser due to rotation variance of reflectance behavior [10]. This leads to different spectral reflectance for different angles of illumination. The spectral reflectance specified by the manufacturer have been measured with an 8° geometry and is applied in our data set for the white patch spectral reflectance correction of SPDs measured with a 45°/0° geometry.

Finally, different scattering by white patch surface roughness might also influence the measurement particularly for huge light exit ports. The lighting source dimension could not be neglected and does not represent an ideal point source. Especially huge lighting such as Bron Kobold Lumax can lead to different scattering/stray light by illuminated target depending on the distances ***a*** and ***b***. The dark noise of the used spectrometer and the scattering light in our measurement setup were considered relatively insignificant. We measured a signal-to-noise ratio of more than 5 orders of magnitude. Stray light was measured to be less than 4 orders of magnitude relative to the signal. As a result, both are below the uncertainty by radiometric and geometric errors discussed above.

Applications

The following applications could benefit from SPDs of our data set. SPDs can be used for the computation of ACES IDT profiles, which requires the spectral power distribution of a given light or even a linear combination of lighting. In particular the IDT profile creation method, which is currently developed by the Open Film Tools camera characterization project [11] at HdM, requires two SPDs to determine the spectral response of camera systems. These SPDs might also be taken from the given data set.

A method for detecting lighting source spectra in an image scene is described in [12]. Our data set can be also considered for classification of such lighting. In addition to that, rental services for cine lighting can evaluate their own measured SPDs against the given data set to evaluate ageing, maladjustment or other defects before using lighting on a film production.

Conclusion

We have presented a database of spectral power distributions of commonly used cine lighting. The SPD data set include measurements of Tungsten, HMI, fluorescence and LED based light sources. The database can be downloaded at the project website [13]. Based upon ISO standard 3664:2000 [9], we have suggested a modified measurement method to ensure fast and easy measurement setup and reproduction of measurement geometry.

SPDs of the database can be used for creation of ACES IDT profiles, for camera characterization and for classification of unknown lighting. The data set can also be employed as a reference in order to compare with lights used in film production. The comparison results can give an indication of technical defects, wrong color temperature and ageing and might be used as a decision base for usage of such lighting.

Acknowledgements

We would like to thank the MFG Foundation Baden-Württemberg at the Medien- und Filmgesellschaft Baden-Württemberg, which funded this work as part of the Open Film Tools project within the Karl Steinbuch Research Programme. We would also like to mention the support by Institute for Large Area Microelectronics - University of Stuttgart, CinePostproduction Berlin and Ingmar Rieger at Stuttgart Media University.

References

[1] Goldstone et al., Procedure P-2009-001 Recommended Procedures for the Creation and Use of Digital Camera System Input Device Transforms, Academy of Motion Picture Arts and Sciences, 2009.

[2] Kino Flo Lighting Systems, Lamp Choices <http://www.kinoflo.com/Top%20Buttons/Kino_U/FAQs.html> (20 March 2015).

[3] General Electric GE Lighting, Spectral Power Distribution Curves <http://www.gelighting.com/LightingWeb/na/resources/tools/lamp-and-ballast/spectral-power-distribution-curves.jsp> (20 March 2015).

[4] OSRAM SYLVANIA, Spectral Power Distributions of SYLVANIA Fluorescent Lamps < http://assets.sylvania.com/assets/documents/faq0041-0800.83f1d8de-3fe1-4d24-a209-d95f6cac74b9.pdf> (20 March 2015).

[5] Joseph Padfield, Spectral Power Distribution (SPD) Curves <http://research.ng-london.org.uk/scientific/spd/> (20 March 2015).

[6] University of Eastern Finland Spectral Color Research Group, Spectral Database <http://www.uef.fi/fi/spectral/artificial-lights> (20 March 2015).

[7] Commission Internationale de L'Eclairage, Colorimetry – Technical Report, 2004.

[8] R. W. G. Hunt, M. R. Pointer, Measuring Color, John Wiley & Sons: Chichester, 2011.

[9] ISO 3664:2000, Viewing Conditions – Graphic Technology and Photography, 2000.

[10] Physikalisch Technische Bundesanstalt Braunschweig, Zur Rotationsinvarianz von Reflexionsnormalen, <https://www.ptb.de/de/org/4/nachrichten4/2006/metro_6.htm>, (2007).

[11] Stuttgart Media University, Camera Characterization <http://www.hdm-stuttgart.de/open-film-tools/english/camera_characterization> (20 March 2015).

[12] S. Alvarez, L. Presa, T. Kunkel and B. Masia, Low Cost Recovery of Spectral Power Distributions, Spanish Computer Graphics Conference – Eurographics, 2014.

[13] Stuttgart Media University, Database of Spectral Power Distribution of Cine Lights <http://www.hdm-stuttgart.de/open-film-tools/english/cinelight_spectra> (20 March 2015).

Author Biography

Andreas Karge (born 1971 in Halle/Saale, Germany) is working on spectral based camera characterization methods in movie production and spectral measurement of cine lighting at Stuttgart Media University. Besides his research he works as a software engineer in the area of printing and proofing color management for GMG GmbH & Co KG in Tübingen. He received his engineering degree in imaging sciences and media technology (2001) and M.Sc. in media informatics (2005) both from University of Applied Sciences Cologne.