Open Film Tools - a Free Toolset for a Spectral Data Based Movie Camera Colour Characterization

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Abstract The Open Film Tools of Stuttgart Media University are a set of open source data, measurement methods, as well as hard- and software aimed for a spectral data based colour characterization in movie production. It considers the spectral characteristics of the three important components for image formation in a scene: the lighting, the camera and the object's reflectance. The toolset consists of three parts: first a extended standardized method for measuring spectra of lighting and a database of cine lighting. Second a low cost hardware design for building a spectroscope attachment for cameras and a measurement procedure using the attachment to estimate the spectral response. And finally, a software for calculating standardized camera colour profiles using the spectral characteristics of the scene. These profiles can be applied to create a device independent colour representation from camera specific movie data. Open Film Tools is a toolset for camera technicians and cinematographers, which is open source and provides a standardized colour correction.

1 Motivation

In digital camera imaging systems the registered image data can be mainly described by a radiometric and optical parameter set. A linear combination of lighting, with a defined spectral power distribution (SPD), is reflected by a number of objects in a scene having specific spectral reflectances (SRO). The resulting luminous flux partially enters the entrance pupil of the camera system's lens having a spectral absorption characteristic. Finally, the image sensor with his spectral sensitivity registers the incident light per pixel through colour filter elements. The electro-optical transfer function and the manufacturer-specific post processing, e.g. the white balance scaling or a logarithmic coding according to Weber-Fechner's law, influences the finally stored digital image data. It can be described as the spectral response of the whole camera system (SRC). Therefore, the encoded image data depends on the spectral characteristics of the lighting, the objects and camera systems. Especially for movie as well as TV-productions, standardized colour information is required. This is particularly due to the fact that movie sequences from different sources are cut together very often for dramaturgical reasons, or maybe different lighting has to be mixed together. Colour constancy and device independent colour representation must be ensured, i.e. the perceived colours for different stimuli must be the same (figure 1). The reference observer is assumed to be the 2° or 10° standard observer defined by the Commission Internationale de l'Éclairage (CIE).

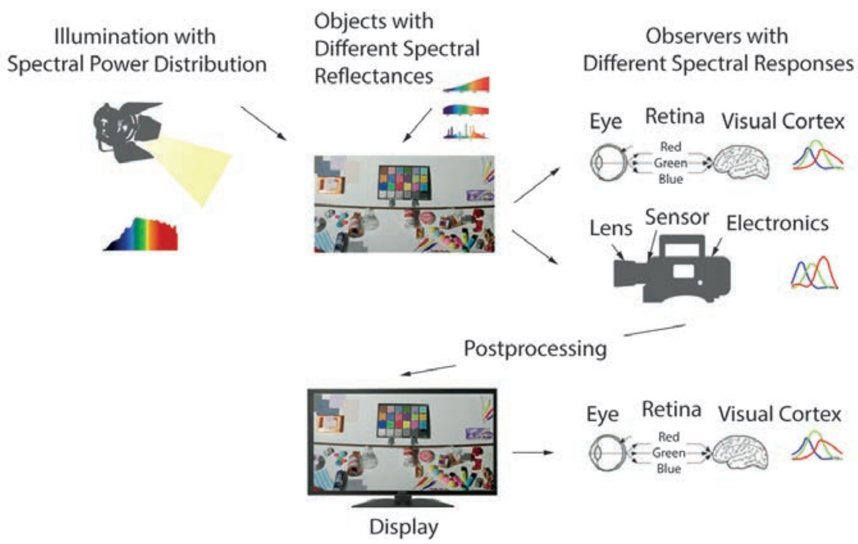

Figure 1: Scene Overview

The movie industry related standardization organization - the Academy of Motion Picture Arts and Sciences (AMPAS) developed a set of standards for a camera device independent colour representation and encoding. It contains a standardized camera independent colour description, based on three independent reference primaries and is defined in the Academy's Colour Encoding System (ACES) [1]. It provides also a standard method for creating camera characterization profiles defined as "Input Device Transformation" (IDT), which contains the recommended creation of a 3x3 transformation matrix. This matrix is based on the spectral characteristics of the scene and converts the tristimuli from a camera specific colour domain into to the device independent ACES colour domain [2]. Such profiles can then be used in movie post-production in a first processing step to ensure all colour information from different sources is represented in the same, i.e.

ACES, colour domain for further production. Unfortunately, only for a few, professional and new camera-models such IDT profiles are available from the manufacturer and no toolset, neither commercial nor free, exists, for creating IDT profiles. Hence the main motivation of Open Film Tools is an implementation of creating such IDT profiles, with a minimum amount of cost and time, in a standardized manner, usable by camera technicians and cinematographers.

2 ACES-IDT Standard for a Device Independent Colour Representation

According to the ACES-IDT creation standard a 3x3 colour transformation matrix $\boldsymbol{B}$ must be determined by the following equation [2]:

$$\boldsymbol{S} = \sum_{\boldsymbol{i}=\boldsymbol{1}}^{\boldsymbol{n}} ||\boldsymbol{f}_{\boldsymbol{CAM}}(\boldsymbol{x}'_{\boldsymbol{i}}, \boldsymbol{w}_{\boldsymbol{ACES}}) - \boldsymbol{f}_{\boldsymbol{CAM}}(\boldsymbol{MBv}_{\boldsymbol{i}}, \boldsymbol{w}_{\boldsymbol{ACES}})|| \qquad (1)$$

The notion is as follows:

$\boldsymbol{S}$ Sum of errors, to be minimized e.g. through Levenberg-Marquardt

$\boldsymbol{n}$ Number of spectral reflectance of objects

$\boldsymbol{f}_{\boldsymbol{CAM}}$ Function converting tristimulus into an equidistant perception domain (defined by standard, e.g. CIE-Lab, CIE-CAM02)

$\boldsymbol{x}'_{\boldsymbol{i}}$ Tristimulus of i^{th} object (defined by spectral reflectance of object, standard observer and standard illumination; adapted chromatically to ACES white point)

w_{ACES} CIE tristimulus of ACES white (defined by ACES standard)

M 3x3 transformation matrix from ACES into CIE-XYZ domain (defined by ACES standard)

v_i Camera tristimulus of i^{th} test patch (derived by SPD measurement of real scene illumination and spectral response of camera system according to measurement standards and the object reflectance as used for $\boldsymbol{x}'_{\boldsymbol{i}}$; target white point normalized)

It must be noticed, that in general the sum of errors is different from zero, solely because most camera systems do not fulfil the Luther condition. Since the creation of an IDT requires numerical data, describing the spectral characteristics of the illumination, the objects and the camera system, we searched for data made public by the respective manufacturers themselves. For cine lighting SPDs are provided but only as simple charts [3][4][5]. Often, in these cases, the used measurement standard was not mentioned. In the case of movie cameras neither spectral sensitivities nor SRCs are published at all. Fortunately, a better situation exists for the set of spectral reflectance of objects. Here we find at first the standard object colour spectra database for colour reproduction evaluation (SOCS) [6]. Beside that, also a set of test charts exist with published spectral reflectance, e.g. the "Color Checker" [7][8].

3 Overview of Open Film Tools

Open Film Tools consists of three main components: the first component, i.e. the spectral characterization of lighting, contains a spectral database of commonly used cine lighting. Here we introduce a new extended standardized measurement method. In order to obtain the spectral characterization of cameras, the second component contains a measurement procedure using a developed low cost spectroscope. Based on the spectral characteristics input, this concludes to the colour characterization as the third component of Open Film Tools. It contains the implementation of ACES-IDT profile creation and a running Web Client/Server for profile creation (figure 2). In the following we will describe this components.

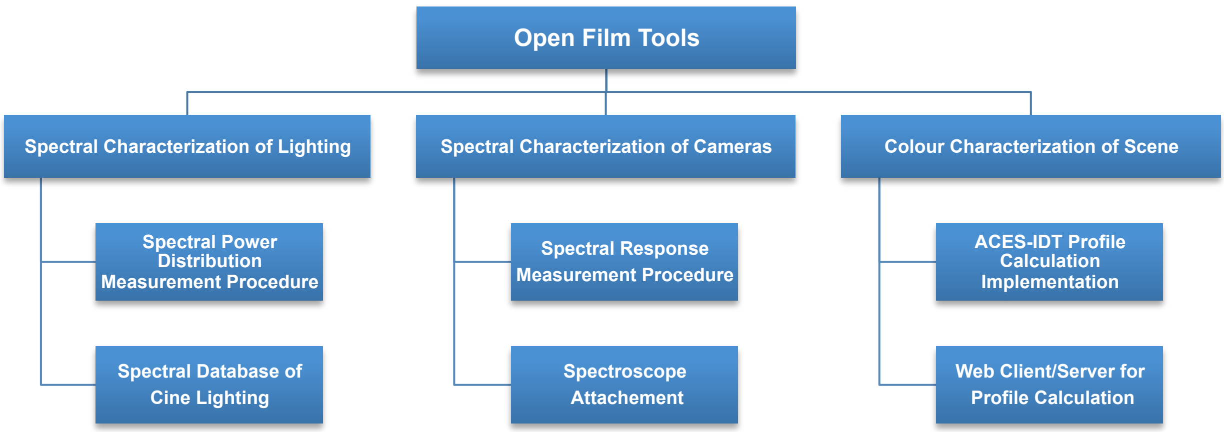

Figure 2: Overview of Open Film Tools

4 Spectral Lighting Characterization Components

A commonly used, standardized measurement method for SPDs of lighting utilises an Ulbricht sphere. This sphere integrates the whole lighting output. The standard is defined by the CIE and known as the 8° geometry [9]. This method has two disadvantages: since cine lighting often have diameters of more then one meter, it leads to an unhandy setup. Also the integration of light does not represent the illumination of objects in a movie scene. Only a small light cone strikes an object element, which is then imaged into a sensor element. Much closer to this real scenario another method is proposed in [10]. Lighting illuminates a white target and the reflected light is then measured by a spectrometer. This approach and a 45°/0° measurement geometry, as described in ISO standard 3664:2000 [11], were chosen. However, this setup leads to the problem of correct, fast and reproducible positioning of a particular light. We found that the out coming light from the light's exit port is in fact not an ideal cone beam with a Gaussian power distribution perpendicular to the optical axis of light forming elements with its maximum on the axis itself. For a number of lighting the maximum is displaced or a local minimum exists at the centre surrounded by two maxima.

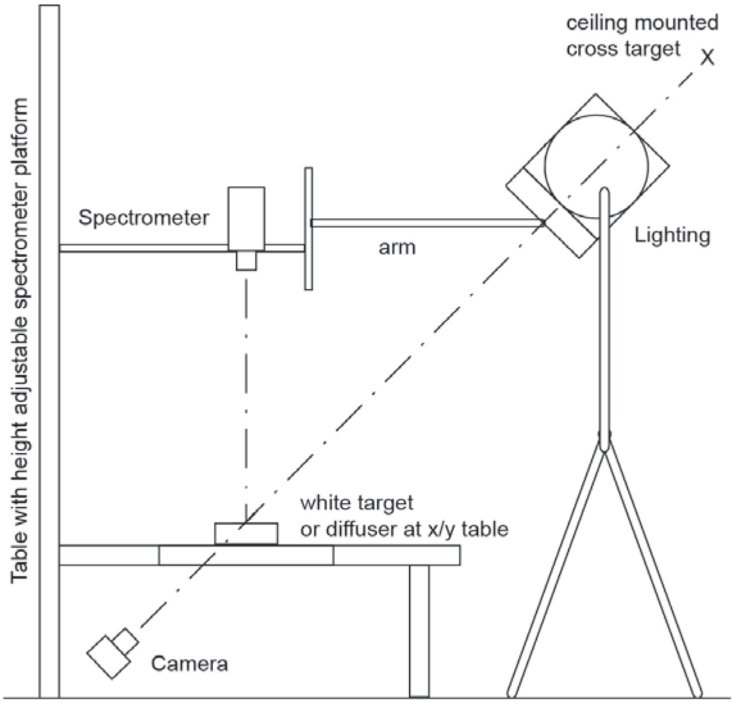

Figure 3: Lighting Measurement Setup

Considering all this, we developed an iterative positioning process in order to achieve that the global maximum or local minimum hits the white target. Figure 3 shows the principal setup with the main components (lighting, spectrometer and white target) and additional elements required for the positioning (camera, arm, diffuser and cross target). The detailed positioning process is described in [12]. Based upon this method a spectral database of cine lighting was created. It contains a cross section of lights based on the most common light emitting principles. They are Tungsten (TU), fluorescence (FL) and metal halide gas discharge lighting (HMI) as well as the now popular light-emitting diode based semiconductor light sources (LED) (table 1). The database is available at [13].

Table 1: Measured Lighting Grouped by Radiation Emitting Principle

	Tungsten	HMI	Fluorescence	LED
ARRI	650+, 1000+, 2000+	D5-1, M40, Daylight Compact, Compact	-	LoCaster, L5-C, L7-C
Bron Kobold	-	Dlf 575	Lumax	-
CMT	-	-	Kinoflo	-
Dedolight	Aspheric 2	-	-	-

Particularly several variations were measured if applicable: full and half power, soft and spot adjustment, with/without diffuser. Some LED lighting also allow the variation of the correlated colour temperature (CCT). In this case SPDs for CCTs representing artificial light and daylight were also measured. Figure 4 and figure 5 show a selection of measured samples.

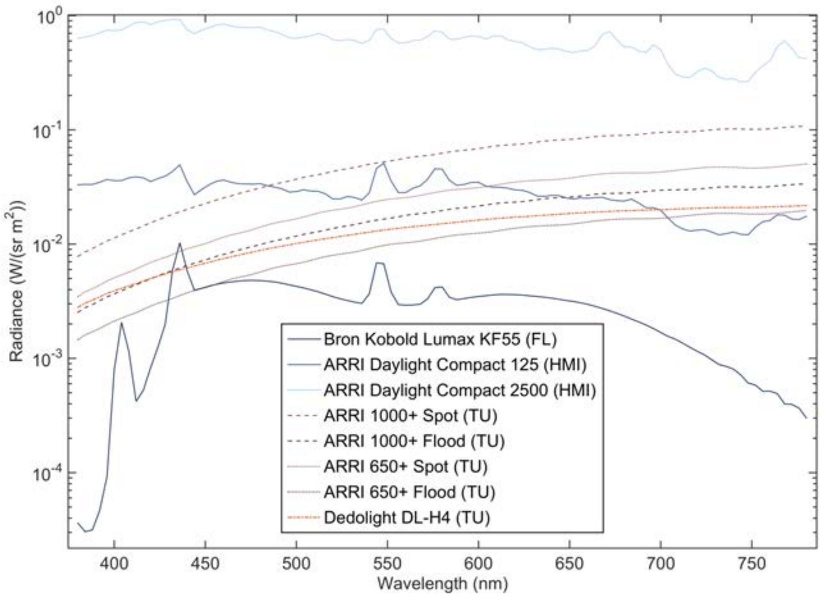

Figure 4: Traditional Lighting Samples

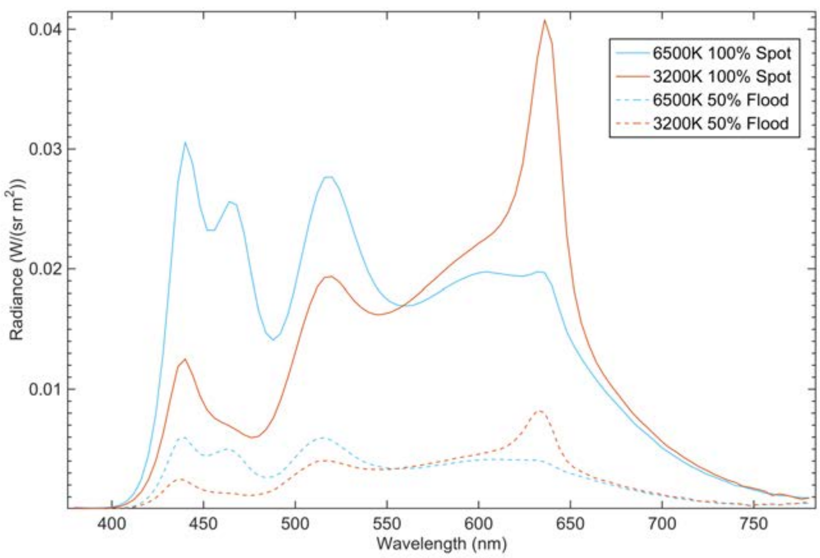

Figure 5: LED Lighting Samples for Different CCTs

5 Spectral Camera Characterization Components

The ACES-IDT standard based camera characterization requires the knowledge of the spectral response of the camera system. As stated, for cine lighting the spectral characteristics of cameras are not available from the manufacturer. Therefore, it must be determined by an own measurement. High accuracy methods to measure the spectral response require a monochromator. Here, the whole sensor is exposed by a spectral intensity in small wavelength ranges step by step for the whole visible spectrum from a stabilized light source. The spectral power distribution is known (i.e. a standard source) or acquired by a measurement with a reference spectrometer or photo diode in place of the image plane. For machine vision this method is standardized in [14]. In movie production current camera characterization standards or recommendations, e.g. [15] or [16], are not define a method for spectral characterization. They are only based on colourimetric values. In order to get the spectral response with less precious or precise devices and time consuming setups, an approach can be used as described in [17]. This method exposes the image sensor plane with the whole spectrum created by dispersive elements. Open Film Tools developed a small slit/grating based spectroscope attachment, which will be positioned in front of a camera system including filters and optics. In contrast to the above-mentioned standard used in machine vision, which measures the spectral sensitivity, this approach measures the spectral response of the whole camera system including the imaging optics. This simplification allows a low cost construction and design. Therefore it takes into account the spectral transmittance of lenses and filters. In figure 6 the principal optical path is shown.

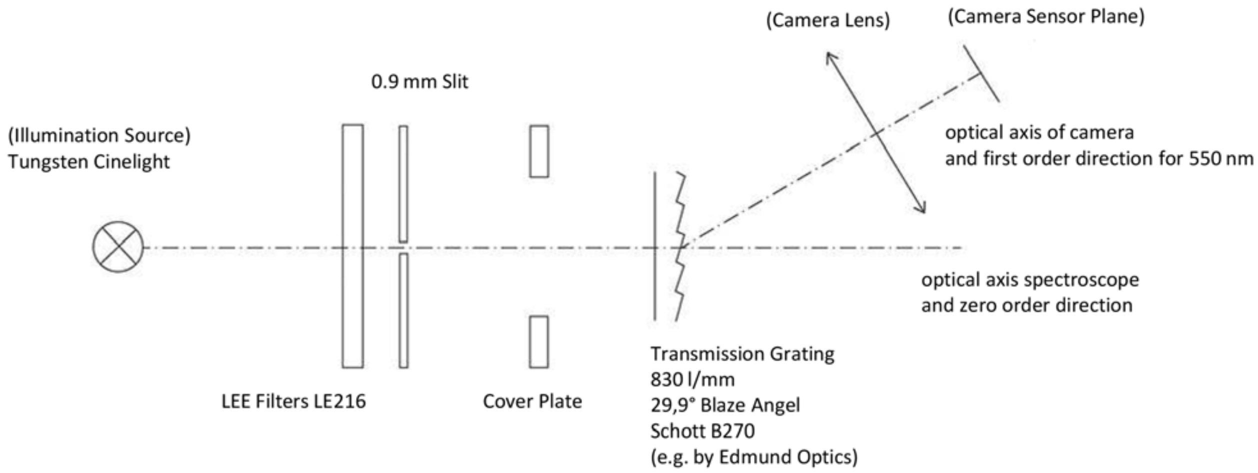

Figure 6: Optical Path Using Spectroscope Attachment

To further simplify the design, we omit a collimating element, which is replaced by a diffusing foil. The spectral resolution is mainly limited by the width of the slit. This is due to the fact, that the image intensity should be approximately 80% of the pixel saturation value by using a standard Tungsten based cine lighting with a power of approximately 150W, which passes the diffusing foil in front of the slit.

The diffraction grating has a spectral resolution of 1 nm. It is recommended that a lens should be used in combination with a camera whereas the spectrum exposes 400 up to 800 pixels in width. This ensures that the slit remains the resolution-limiting element. Furthermore a 3D-printable case for the optical elements was designed (figure 7). It also allows the user to adept it to different lens mounts.

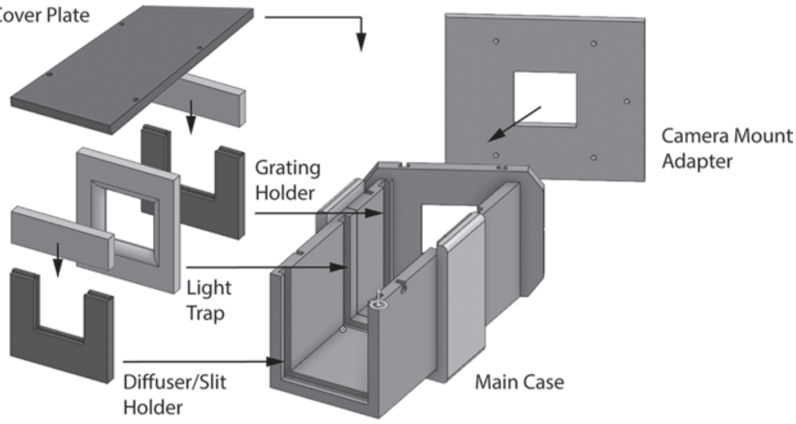

Figure 7: Spectroscope Case Design for 3D-Printer

The list of required optical elements, the 3D printer files and the construction manual are available at [18]. To measure the spectral response, the setup requires following components: the spectroscope mounted camera system, two lighting, a Tungsten based light and a fluorescence or LED based light with significant lines, and a reference spectrometer. A principal measurement setup is shown in figure 8.

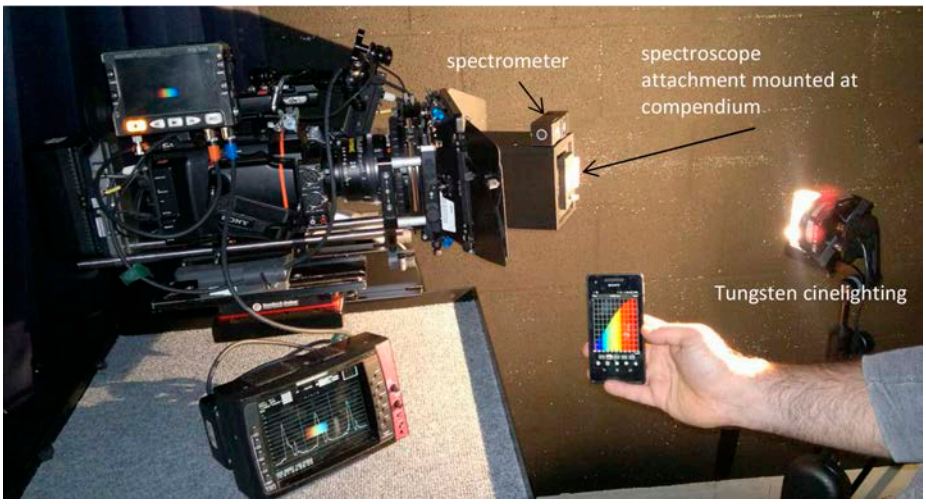

Figure 8: Measurement Setup Example

For the Tungsten and the line light we twice do the following for an actual measurement process: we capture an image of the light source and simultaneously take a spectrometer reference measurement. For both light sources the maximum spectrum image value must be approximately 80 % of maximum pixel value. Varying the distance of the light in front of the spectroscope attachment allows the adjustment of this value, while the stop of the lens should be at a constant value.

The spectrometer should be positioned near to the attachments light entrance port. Overall we now have four data captured: images for both light sources and two reference SPDs respectively. The detailed measurement setup and process can be found at [18]. These four files are the input for the software for camera characterization in order to determine the spectral sensitivity. The algorithm currently requires linearized camera images; therefore non-linearized image data must be linearized using the same processing pipeline as later in movie production.

6 Colour Characterization Components

The Open Film Tools software is a client/server-based application for ACES-IDT profile creation. It first estimates the camera systems spectral sensitivity with the measured data described in last chapter. In a second step it uses this computed spectral characteristic of the camera, the SPD of scene illumination and the spectral reflectance set of objects to create a profile. Figure 9 shows the web client browser user interface.

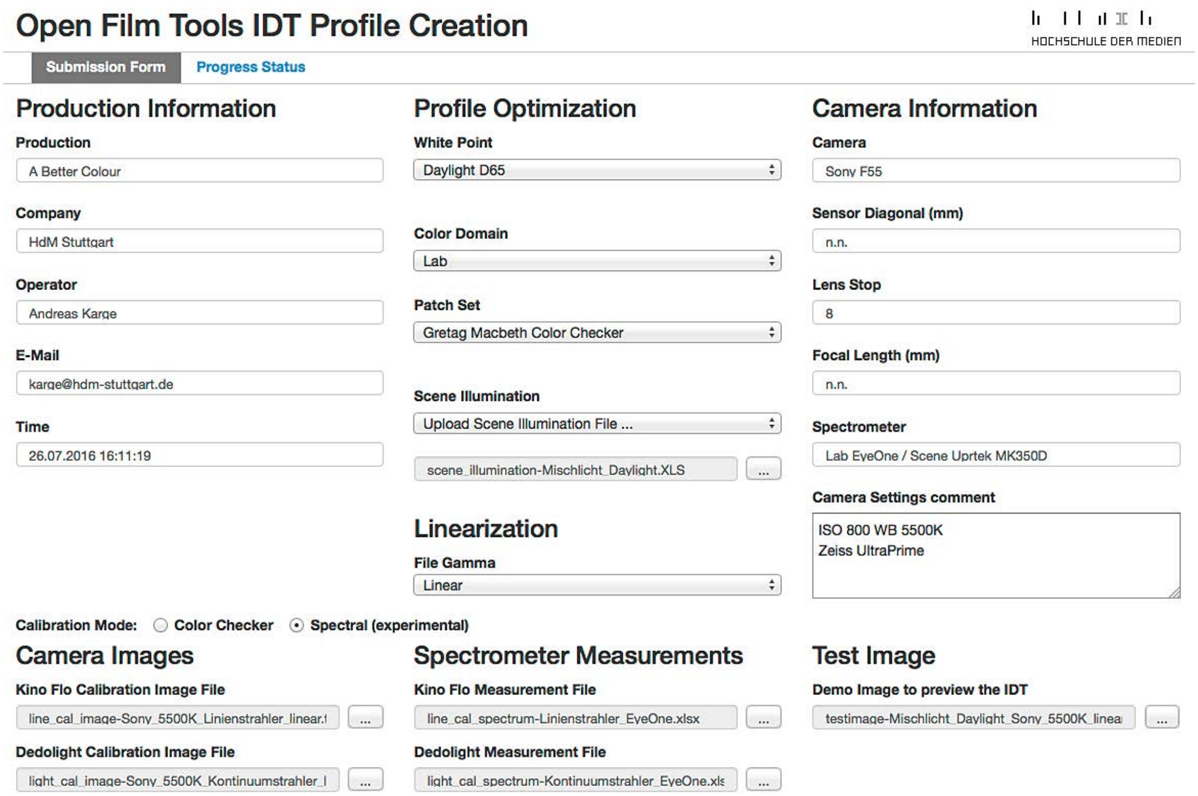

Figure 9: Open Film Tools Web Interface for ACES-IDT Profile Creation Parameter Set (Kino Flo as Line Light, Dedolight as Tungsten Light)

At the end the user gets a file with the spectral response of the camera system, an IDT profile and optionally a profiled test image. While the web client/server is based on PHP, the profile server is based on MATLAB. The code base is available at GitHub [19]. A running installation for profile creation can be found at [20]. The principal overview of the data flow and modules is shown in figure 10. The application also allows the Color Checker chart based profile creation method.

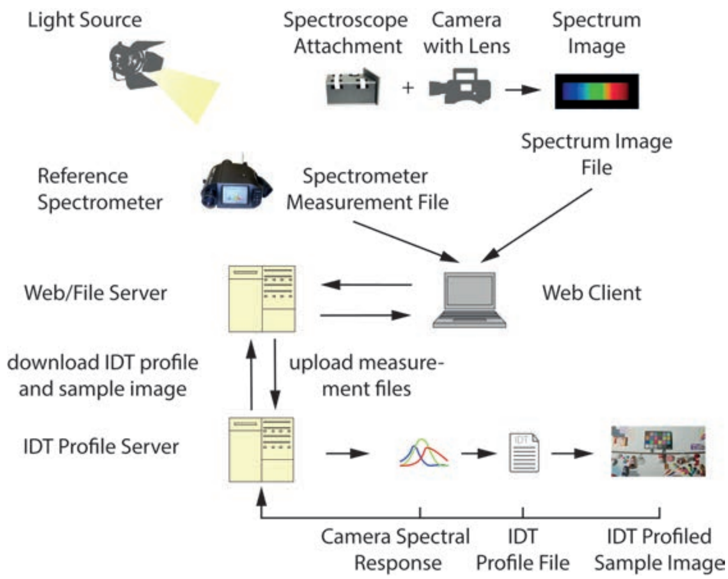

Figure 10: Architecture of Profile Creation Software

7 Results of Open Film Tools Application

To evaluate the spectral data based colour characterization, first we verified the result of the estimated spectral response by using the spectroscope attachment. Figure 11 shows for example the result by Open Film Tools in comparison to the manufacturer's curve for an ARRI Alexa using a ZEISS UltraPrime, and the curves for the EBU reference camera [7].

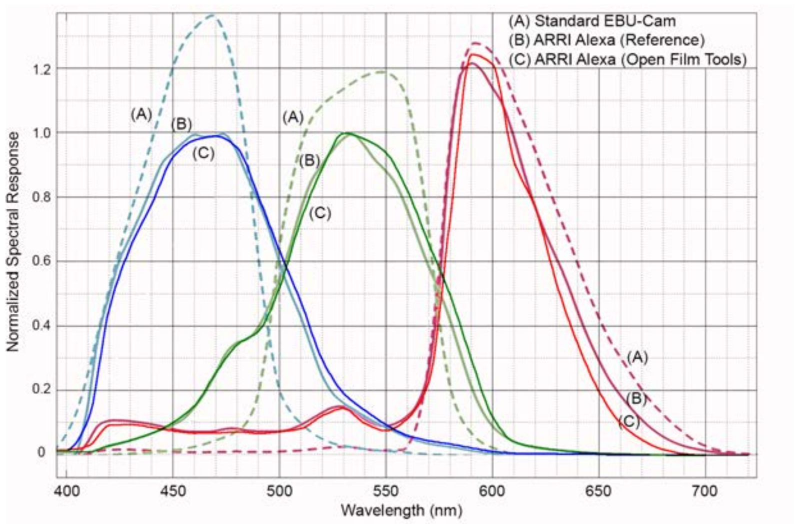

Figure 11: Estimated Spectral Response of ARRI Alexa

While characteristic local minima and maxima and inflexion points of the curves are comparable, it does not allow the evaluation of the resulting colorimetric error. Therefore, additionally the CIE-Lab reference values of the Color Checker patches were compared with the values of the image after applying the spectral data based IDT profile. Also profiles were computed by using the camera patches values directly, i.e. the conventional, non-spectral Color Checker chart based method. The CIE-ΔE_{2000} difference of reference and profiled values for all patches are comparable for both applied profiles. The CIE-ΔE_{2000} differences between the two profiled images for each patch are below of 0.4.

Finally we compared profiled images using two different spectral data based profiles with a target illuminant of D50. Both use the estimated spectral response of the camera system, but one uses the equivalent standard illuminant of the related CCT of the scene illumination and the other one the SPD of the scene illumination.

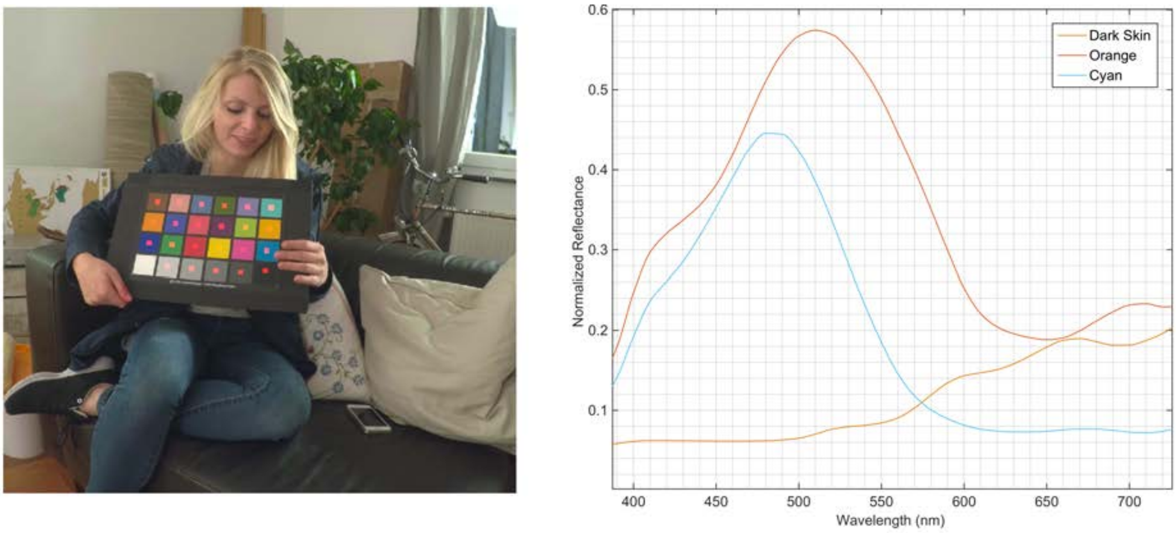

Figure 12: left - GoPro Hero 4+ Image Sample Area with Detected Color Checker Patches (© Baumgartner/Heinlein/Joeck/Schmutzler); right - Three Selected Patches Reflectances

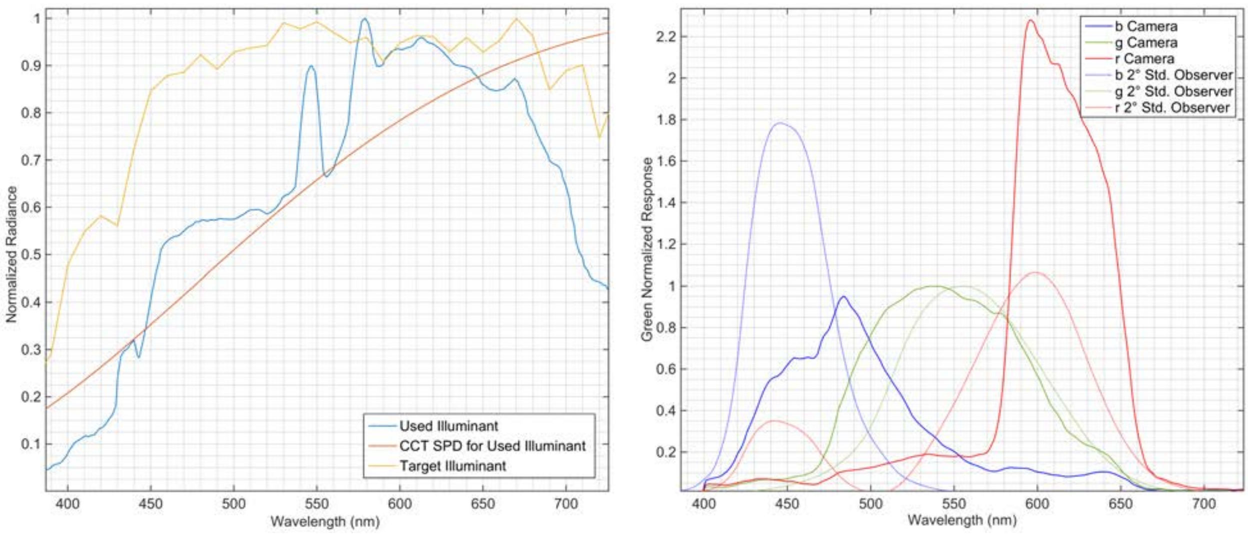

Figure 13: left - SPDs of Real Scene Illumination, CCTs Scene Illumination and Profile Target Illuminant of D50; right – Estimated Spectral Response of GoPro Hero 4+

Figure 12 left shows a profiled image of a GoPro Hero4+ (Protune mode with native white balance and ISO 800). The scene was illuminated by mixed Tungsten and HMI Lighting (figure 13 left: Used Illuminant). The estimated camera response for the camera is shown in figure 13 right. In Table 2 the results for three selected Color Checker patches (figure 12 right) of the profiled sample image are shown. They have a perceptible improvement using the real scene SPD instead of the CCT equivalent illuminant's SPD (figure 13 left: CCT SPD of Used Illuminant).

Table 2: CIE-Lab values of selected Color Checker patches after applying the IDT profiles using the CCT equivalent illuminant's SPD (CCT) vs. real scene SPD (spec); $\Delta E2000_{CCT}$ for CCT based profiled image compared to reference values; $\Delta(\Delta E2000)_{spec\text{-}CCT} = \Delta E2000_{spec} - \Delta E2000_{CCT}$

	L_{CCT}	a_{CCT}	b_{CCT}	L_{spec}	a_{spec}	b_{spec}	$\Delta E2000_{CCT}$	$\Delta(\Delta E2000)_{spec\text{-}CCT}$
Dark Skin	44.65	10.74	24.44	44.58	11.31	23.49	9.21	-0.70
Orange	67.88	30.75	68.00	67.72	32.27	63.25	6.76	-1.77
Cyan	48.50	-16.68	-23.55	48.69	-17.94	-22.41	6.18	-0.60

A better skin tone and orange reproduction is mainly influenced by the significant different SPDs in the range of longer wavelengths. The cyan patch improvement primarily relies in the different CIE-Y primary values, wherein the SPD of the real illumination with its two significant lines are incorporated. The mean improvement for this sample for all Color Checker patches of the spectral vs. CCT equivalent data based method is CIE-ΔE_{2000} = 0.29.
Additionally we tested the influence of lens transmittance and its correction by applying the computed IDT profile. Figure 14 shows two profiled images of same raw image captured with an ARRI Alexa using a yellowish Bausch&Lomb lens. While left profiled image uses a standard IDT profile, the right image is profiled with an IDT profile, which takes the lens transmittance in to account.

Figure 14: Lens Transmittance Correction[1]

8 Conclusion and Outlook

An essential requirement for a standardized camera independent colour image representation is the knowledge about the spectral characteristics of lighting, objects and camera system during image acquisition. Data on spectral reflectance

[1] Art Work by Bo Regard - www.appreciating-art.de

of objects, respectively charts, are publicly available. But the manufacturer does most often not publish information about the spectral power distribution of lighting and spectral response of cameras. The Open Film Tools closes this gap for the movie industry. The toolset consists of free and open source components for a spectral characterization: a spectral database of commonly used cine lighting, measured in a standardized manner and a low cost hardware for estimating the spectral response of camera systems. Using this spectral data the Open Film Tools also provides free software creating standardized ACES-IDT profiles. These profiles allow the conversion of the device specific image data into a device independent colour domain. First results demonstrate the improvement using spectral data for the transformation matrix based ACES-IDT profile creation. But the full advantage of working with spectral data will be achieved with look up tables, e.g. described in [21]. This LUT approach will be part of next investigations applying the further developed Open Film Tools.

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