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

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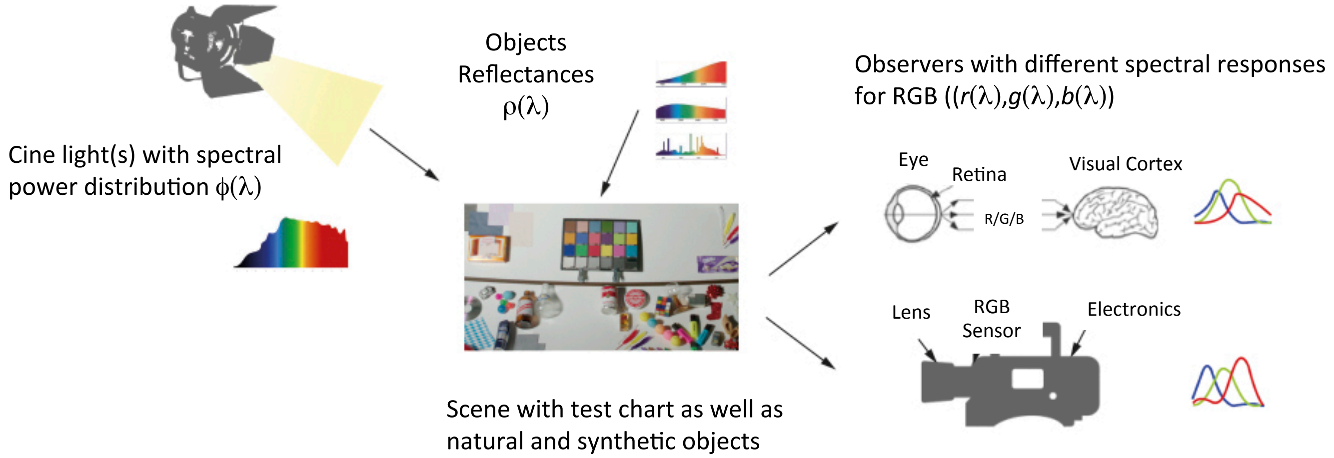
Outline

- From spectra to colours – the situation in movie production
- Open Film Tools – the Components
- Results of applying Open Film Tools
- Conclusion and outlook

From Spectra to Colours in Movie Production



- The colour F with the *R/G/B* values in the image elements depends on spectral characteristics of lighting, objects and observer:

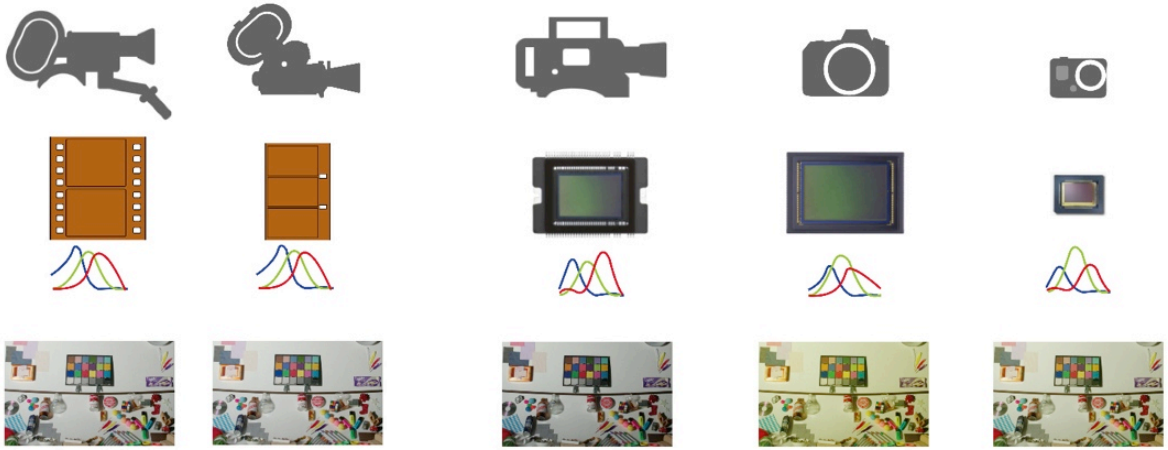
$$F = \begin{pmatrix} R \\ G \\ B \end{pmatrix} \sim \begin{pmatrix} \sum(\phi(\lambda_i)\rho(\lambda_i)r(\lambda_i))\Delta\lambda \\ \sum(\phi(\lambda_i)\rho(\lambda_i)g(\lambda_i))\Delta\lambda \\ \sum(\phi(\lambda_i)\rho(\lambda_i)b(\lambda_i))\Delta\lambda \end{pmatrix}$$

From Different Cameras to Same Colour - the Manual Way

- While lighting and objects are the same, in movie production a set of different camera systems is used and the material is combined for final movie

Past

analogue cameras using same silver halide emulsion



Present

digital cameras with different sensors, electronics and post processing

- **Problem:** manual colour correction for each camera's movie files in post production, in order to ensure same colour perception

From Different Cameras to Same Colour - the Standardized Way

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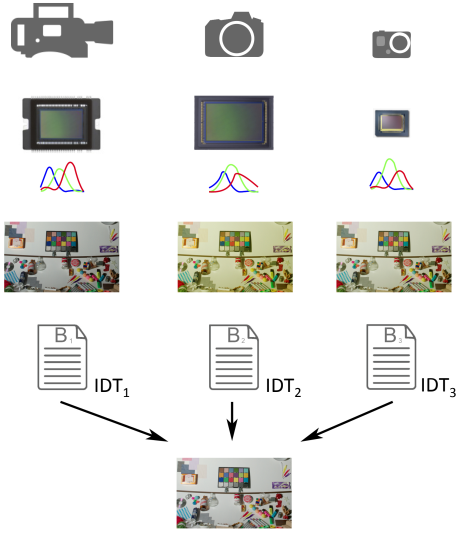
- A camera specific colour $\boldsymbol{F_1}$ can be transformed in a device independent colour $\boldsymbol{F_2}$ by using a conversion matrix $\boldsymbol{B}$:

$$\boldsymbol{F}_2=\begin{pmatrix}R_2\\G_2\\B_2\end{pmatrix}=\begin{pmatrix}aR_1+bG_1+cB_1\\dR_1+eG_1+fB_1\\gR_1+hG_1+iB_1\end{pmatrix}=\begin{pmatrix}a&b&c\\d&e&f\\g&h&i\end{pmatrix}\begin{pmatrix}R_1\\G_1\\B_1\end{pmatrix}=\boldsymbol{B}\,\boldsymbol{F}_1$$

- The „Academy of Motion Picture Arts and Sciences“ (AMPAS) developed a standard for creating such a matrix $\boldsymbol{B}$
- It is stored in an ACES-IDT profile file (**A**MPAS **C**olour **E**ncodings **S**ystem - **I**nput **D**evice **T**ransforms)
- **Solution:** automatic colour correction for each camera’s movie files in post production using ACES-IDT profiles



ACES-IDT Profile Creation Parameter Set

- We are looking for the linear 3x3 matrix B by a solution for following problem:

$$S = \sum_{i=1}^{n} ||f_{CAM}(x'_i, w_{ACES}) - f_{CAM}(MBv_i, w_{ACES})||$$

S	Sum of errors, to be minimized e.g. through Levenberg-Marquardt algorithm
n	Number of spectral reflectance of objects
f_{CAM}	Function converting tristimulus into an equidistant perception domain (e.g. CIE-Lab, CIE-CAM02)
x'_i	Tristimulus of i^{th} object (defined by SPD of standard illuminant, spectral reflectance of object, spectral response of standard observer; adapted chromatically to ACES white point)
w_{ACES}	CIE-XYZ tristimulus of ACES white point
M	3x3 transformation matrix from ACES into CIE-XYZ domain (defined by ACES standard)
v_i	Camera value of i^{th} object (derived by SPD of real scene illumination, spectral reflectance of object, spectral response of camera; target white point normalized

The Motivation for Open Film Tools

- Currently no tool exists for creating ACES-IDT profiles, only a small amount of ACES-IDT profiles for professional cameras exists.

- *ACES-IDT creation requires spectral data, but where you can get it?*

    - spectral characteristics of lighting and cameras are not published by manufacturers

    - Fortunately for objects there are several spectral data sets available, e.g. the ISO/TR 16066:2003 standard object colour spectra database for colour reproduction evaluation (SOCS) or test charts like Color Checker.

Open Film Tools - Components

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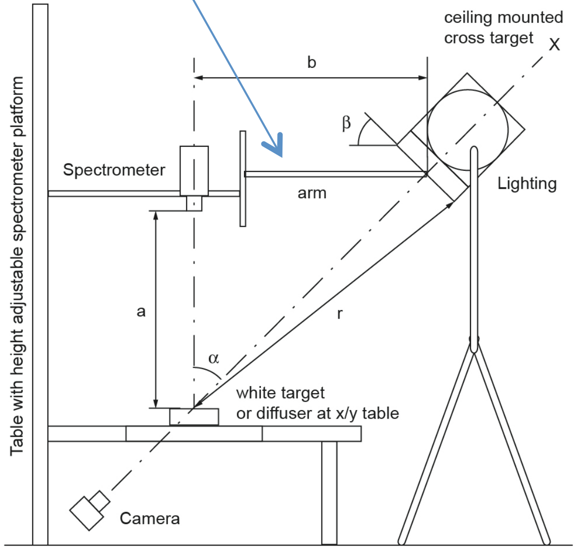
- Open Film Tools
  - Spectral Characterization of Lighting
    - Spectral Power Distribution Measurement Procedure
    - Spectral Database of Cine Lighting
  - Spectral Characterization of Cameras
    - Spectral Response Measurement Procedure
    - Spectroscope Attachement
  - Colour Characterization of Scene
    - ACES-IDT Profile Calculation Implementation
    - Web Client/Server for Profile Calculation

- The components closes the gap of missing spectral characteristics and provide a free usable ACES-IDT profile creation.

Spectral Characterization of Lighting - Measurement Setup Process

- ISO 3664 45°/0° geometry

Image of centered lighting exit port



1) Adjust length and position of arm for a given distance of **b**

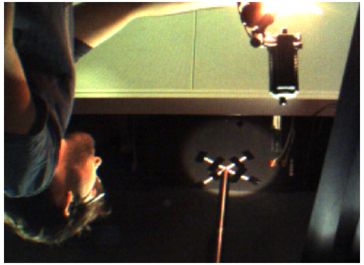
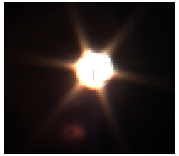


Image of cone end of arm centered at cross target

Image of lighting exit port to be centered after power on



2) Adjust lighting position to center of camera image which is congruent to cross target

Iterative loop

3) Horizontal/vertical adjustment for maximum intensity at patch center (with diffuser in front of camera)

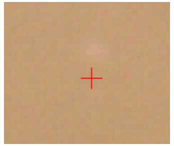
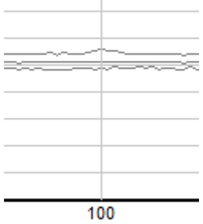


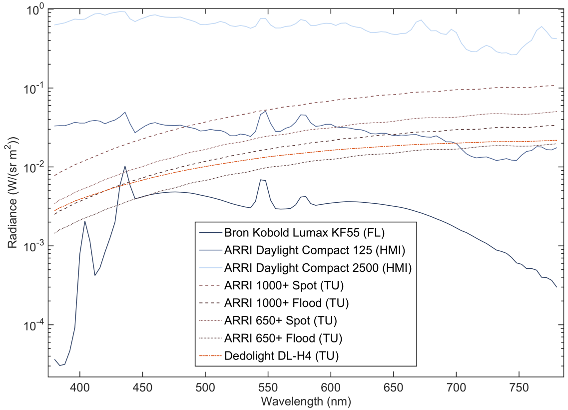
Image with diffuser in front of camera

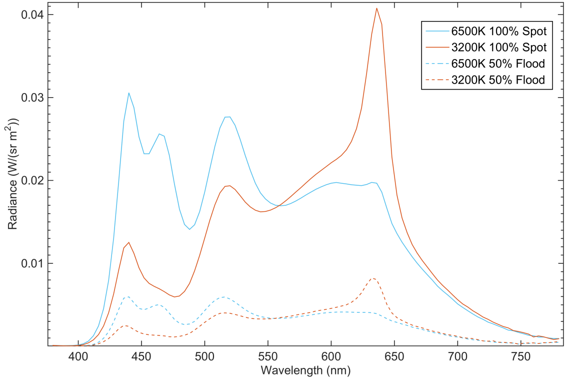


Related Intensity Distribution

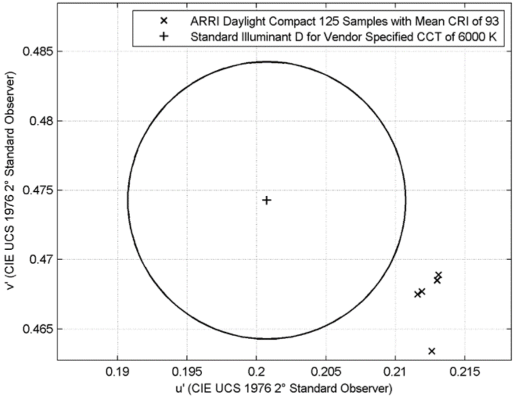
Spectral Characterization of Lighting
- a Database of Commonly Used Cine Lighting

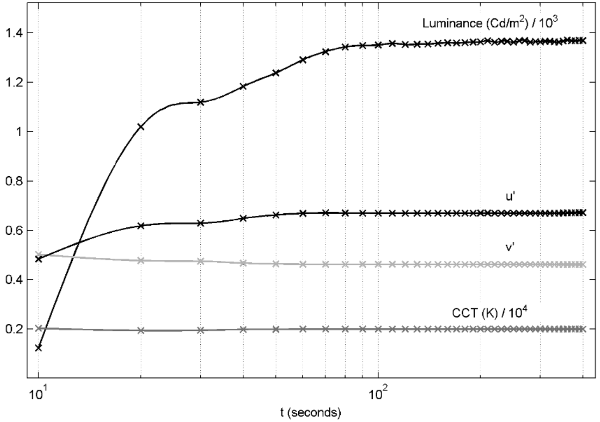
- We measured Tungsten (TU), fluorescence (FL), metal halid gas discharge (HMI) and light-emitting diode based (LED) cine lighting.
- If applicable measurements were done for spot and flood reflector positions (samples in top figure), 50/100% power and variation of CCT (LED lighting based samples bottom figure).
- This dataset can be used for ACES-IDT profile creation as the SPD of illumination.





Measured Lighting – Colourimetrical Evaluation Samples



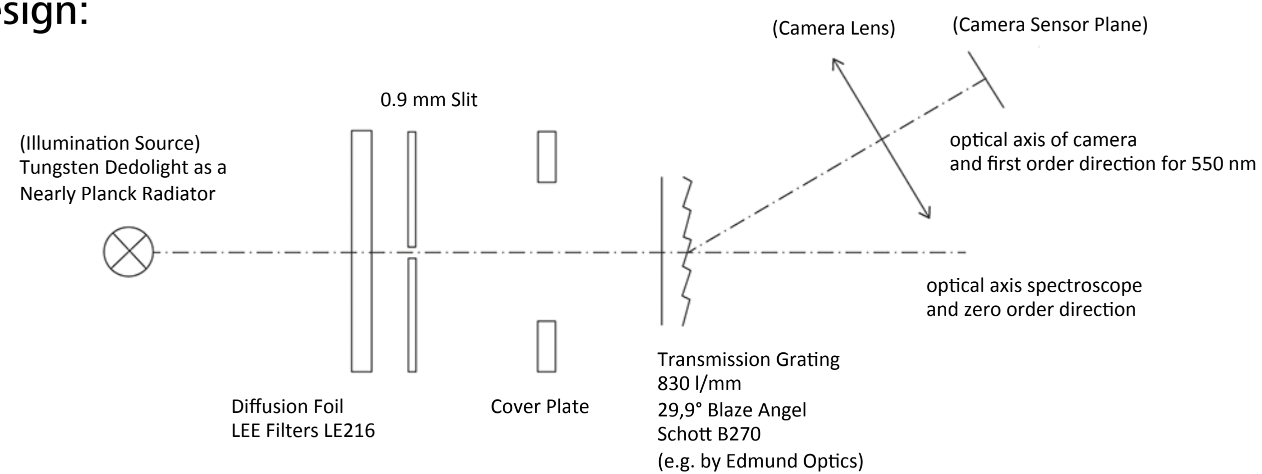


- Figure above shows ARRI Compact 125 Samples CIE **u' v'** values.
- They are outside of the just noticable difference (JND – circle line) of 0.01 of the equivalent standard D illuminant daylight color temperature based values specified by the manufacturer.
- Measurements were done during the power-on phase to evaluate the transient phenomenon.
- Above Figure shows the luminance, the CCT, and the CIE **u'v'** coordinates of the first 6.5 minutes after power-on for an ARRI Compact 1200.

Spectral Characterization of Cameras - the Spectroscope Accessory

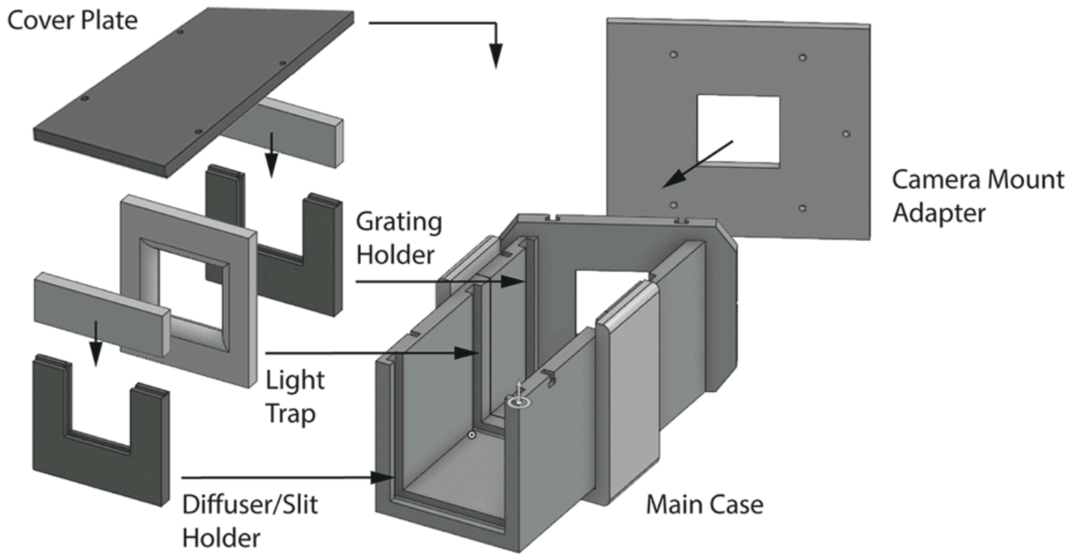
- The precise monochromator based measurement of the spectral response is expensive and time consuming.

- We developed a low cost/less precise measuring device, using a slit/grating combination attached in front of the cameras lens. Figure below shows the principal optical design:



Spectroscope Accessory Case Components

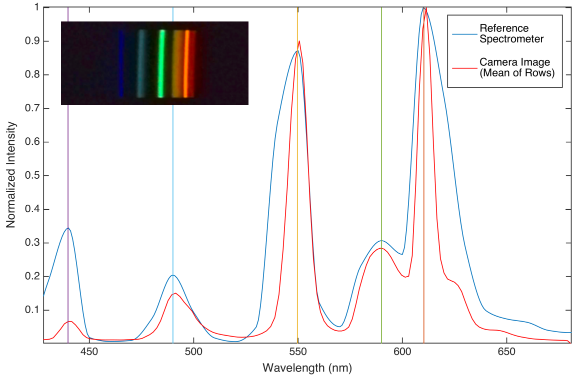
- The optical components are placed in a 3D-printable case (Figure below).



Estimating the Camera Spectral Response

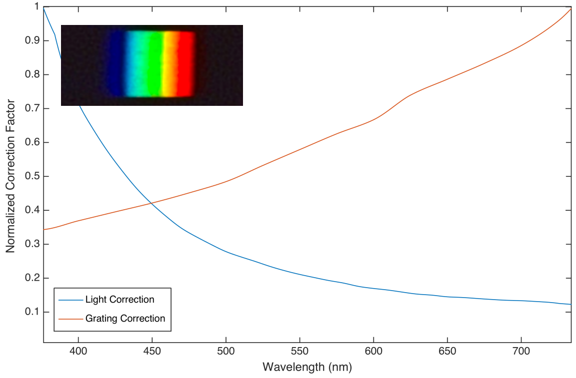
(1) Geometric Calibration with Line Lighting

- Estimating the pixel to wavelength mapping function by using distinct lines (spectrometer reference measurement)



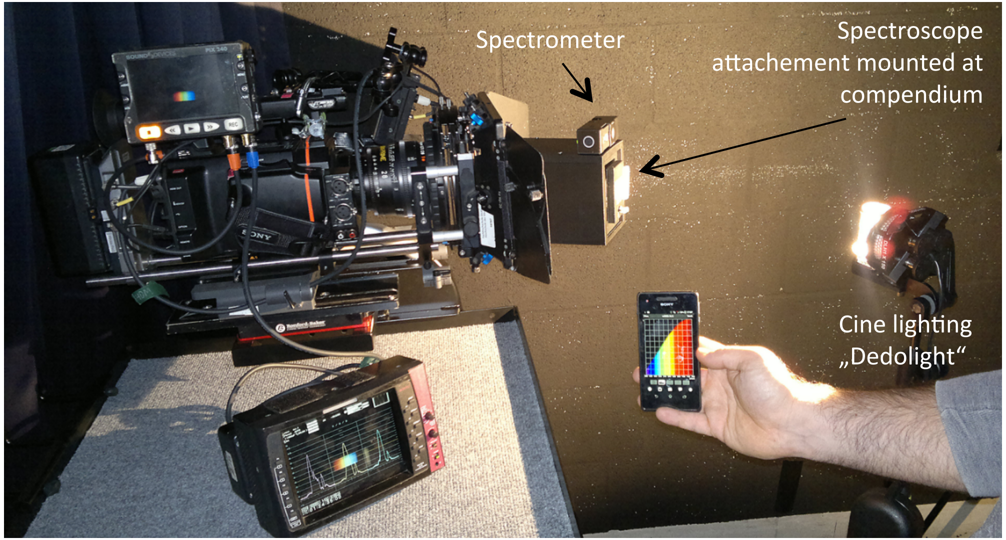
(2) Radiometric Calibration with Tungsten Lighting

- Correction for grating efficiency (provided by manufacturer) and SPD of illumination (spectrometer reference measurement)



Spectral Camera Response Measurement Setup Example

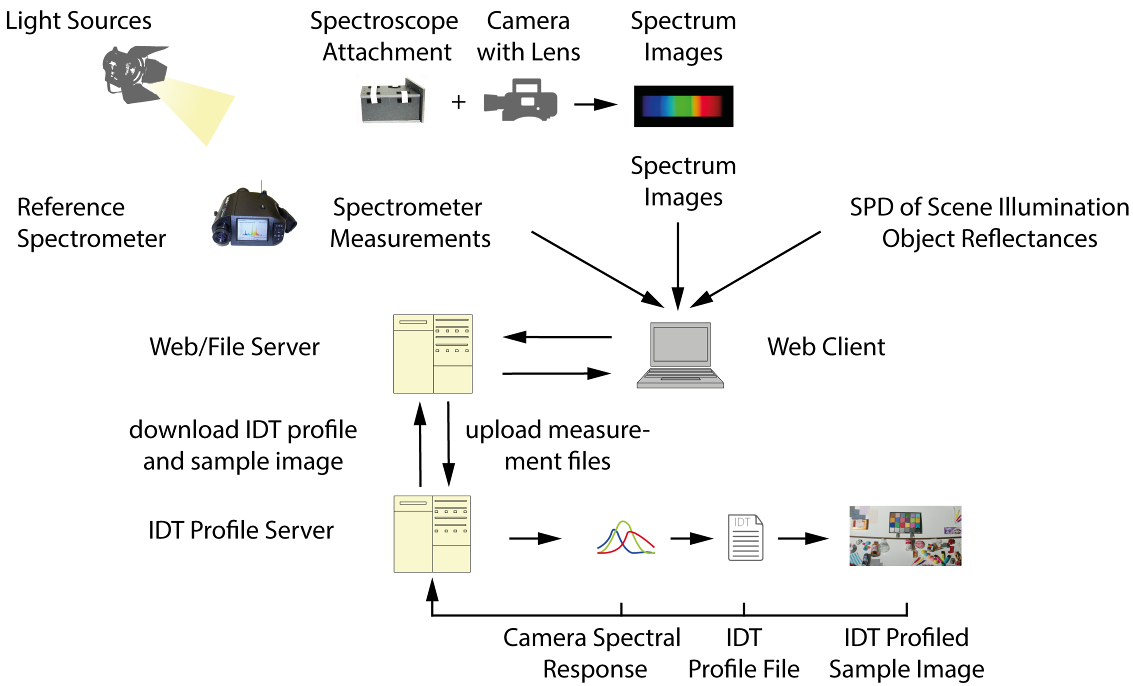
- Sony F camera with spectroscope and reference spectrometer (UPRTek Compact MK350D), a Dedolight as light source (Figure below). The reference measurement is triggered by a smart phone.



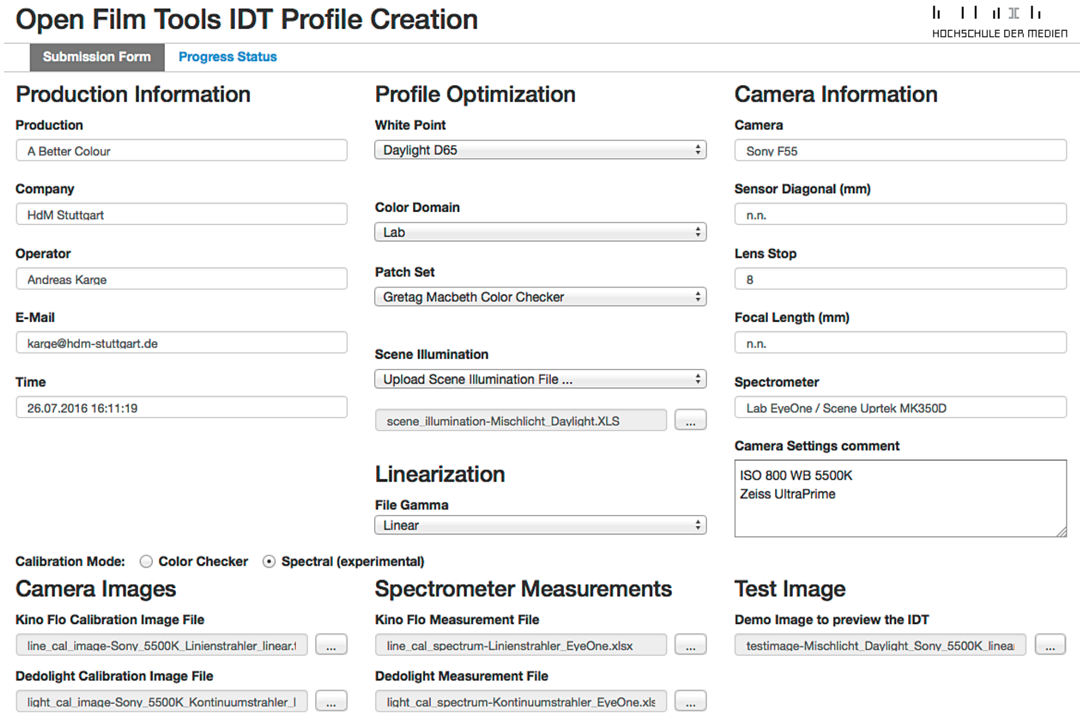
Measurement Procedure Output

- Four measurement files:
  - Two image files (8/16bit int or float tif, dpx) for line and continuum light source
  - Two spectrometer measurement files (i1 Share or UPRTek table layout csv/xls files) for line and continuum light source
- If image data is not linearized, then you have to linearize the image files before the calculation of the camera profile using same workflow as in later movie production.
- Optionally a reference image (8/16bit int or float tif, dpx) preprocessed by same workflow

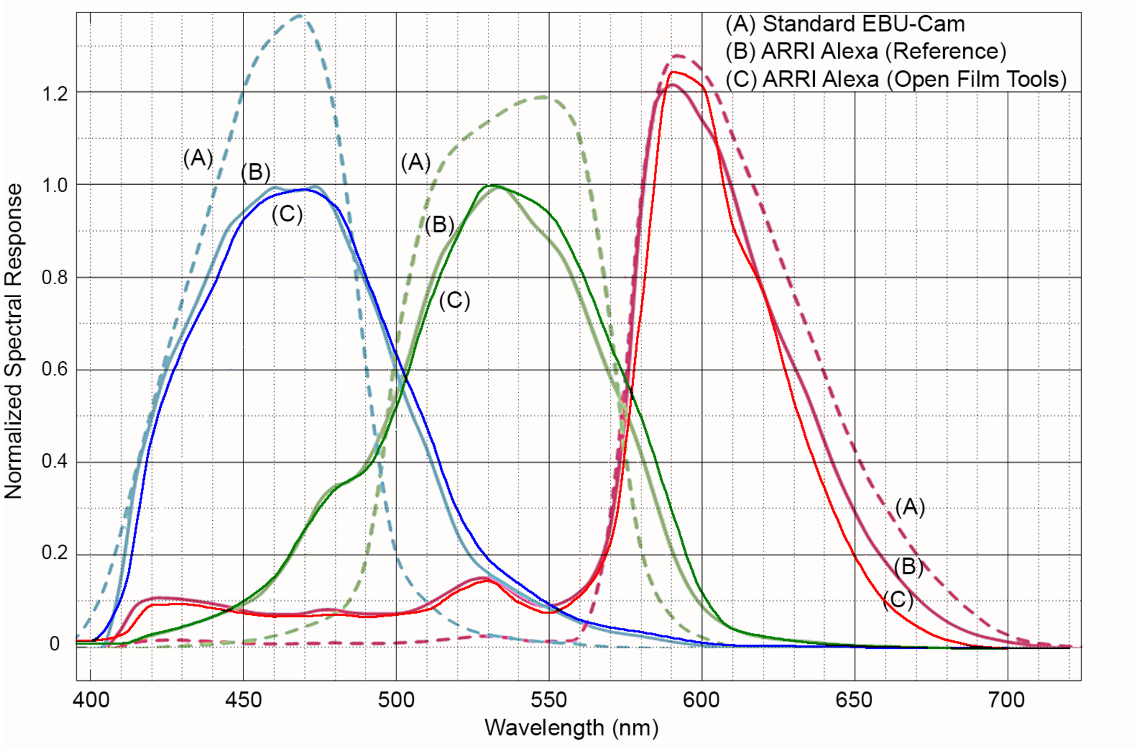
Colour Characterization of Scene
- an Application to ACES-IDT Profile Creation



The Web Client Interface at cam-char.hdm-stuttgart.de



Results of Applying Open Film Tools - Estimated Spectral Response for Arri Alexa



Spectral vs. Chart Based Method

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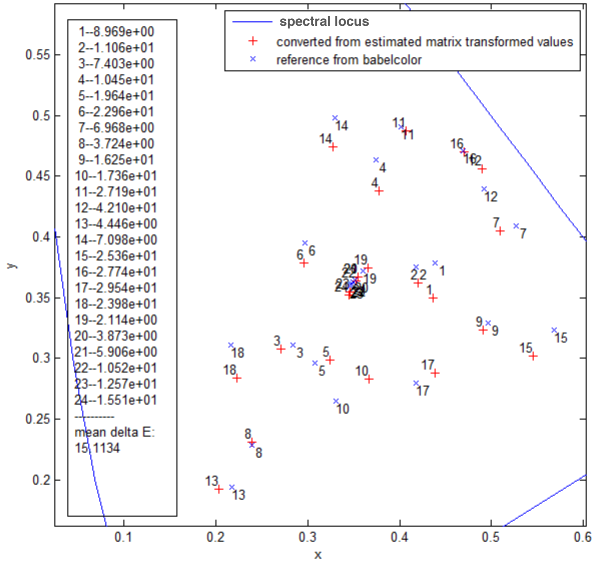
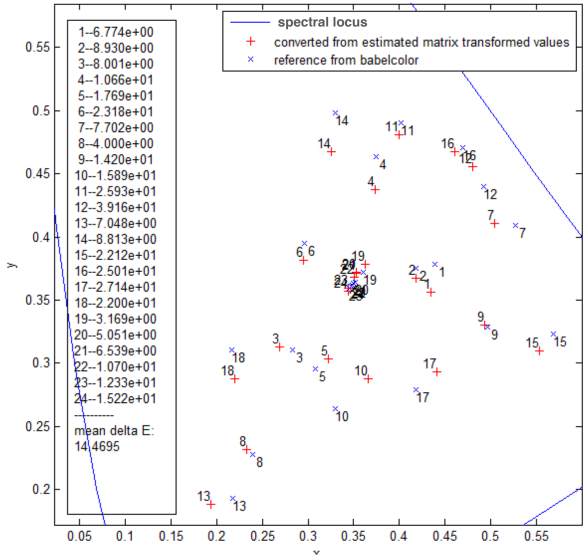
- We got comparable ΔC values (the lightness is not normalized), for spectral based method a value of 8 vs. CIE-Lab based value of 7.5 - sample for Point Grey FL2-03S2C/Sensor Sony ICX424AQ illuminated with Tungsten light

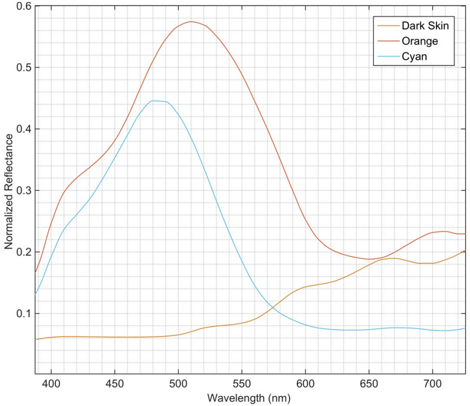


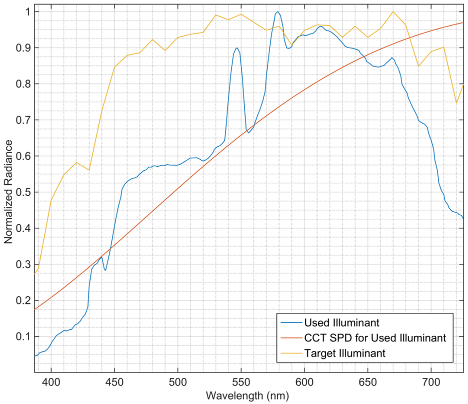
Chromaticity coordinates – Spectral based estimation for Color Checker patches

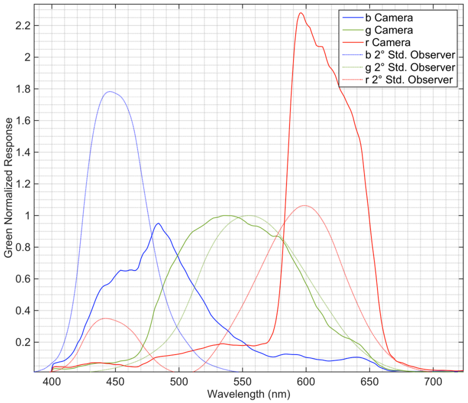


Chromaticity coordinates – Lab based estimation for Color Checker Patches

Better Matching for Mixed Scene Illumination







- GoPro Hero Sample of a scene (left top)
- Mixed Scene illumination (left bottom – Used Illuminant)
- Estimated camera response (right bottom – Camera)
- Comparing ACES-IDT profiled images, using the real scene illumination (spec) and correlated colour temperature based equivalent radiation (CCT SPD for used Illuminant)
- Improvement examples: three Color Checker patches (left right) CIE-Lab values, the ΔE2000 to the CIE standard observer and the Δ(ΔE2000) improvement (table below)

	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

Profiled Images Showing Influence of Lens Transmittance

ARRI Alexa with Zeiss UltraPrime

ARRI Alexa with Bausch & Lomb

Art Work by Bo Regard (www.appreciating-art.de)

Profiled Images Showing Influence of Lens Transmittance

ARRI Alexa with Zeiss UltraPrime

ARRI Alexa with Bausch & Lomb

Art Work by Bo Regard (www.appreciating-art.de)

Conclusion and Outlook

- Open Film Tools as an open source toolset:
  - Providing spectral characterization of lighting and cameras
  - Enables standardized colour correction for a better matching camera colours to the human perception
- What will be done next?
  - Apply OFT created IDT profiles in first movie production
  - Research other colour mapping methods than error minimization
  - Convince the movie industry for using a standardized colour domain first

Acknowledgements

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    - University of Stuttgart, Institute for Large Area Microelectronics
    - CinePostproduction GmbH
    - GMG GmbH & Co KG

- Special thanks to the Tübingen artist Bo Regard for providing his art work.

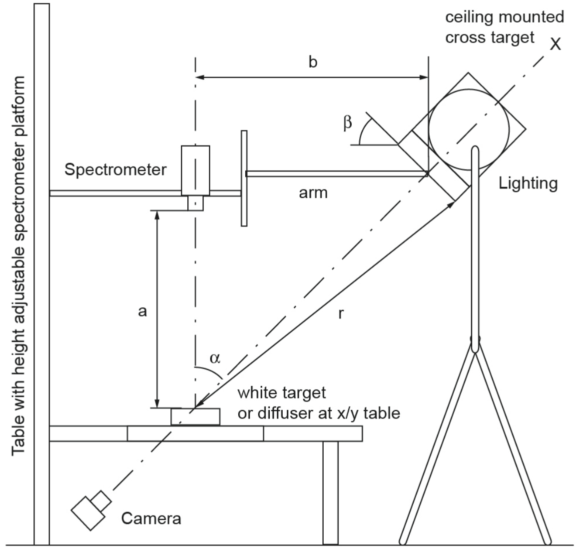
Open Film Tools
-
A Set of Colour Management Tools for Cinematographers

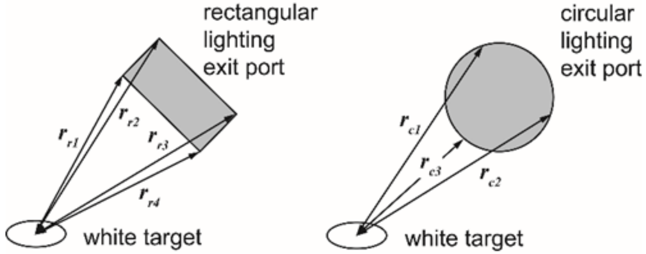
www.hdm-stuttgart.de/open-film-tools

Supplemented Materials

www.hdm-stuttgart.de/open-film-tools

Measurement Setup
- Geometry and Placed Components





a vertical distance from the white patch surface to the front of the spectrometer lens

b horizontal distance from the optical axis of spectrometer to the center of the maximum vertical illumination aperture

r distance from the white patch surface to a corner edge point of the lighting exit port (r_{r1}-r_{r4} or r_{c1}-r_{c3})

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

Measurement Setup
- Used Parameters and Components

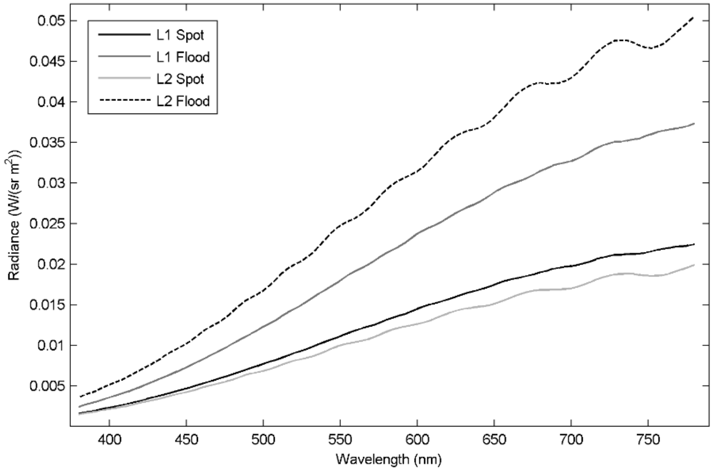
- We used a distance from white target to spectrometer ***a*** =1m. The horizontal distance ***b*** is variable in a range of 1 to 2.5 m related to dynamic range of spectrometer and power of lighting.

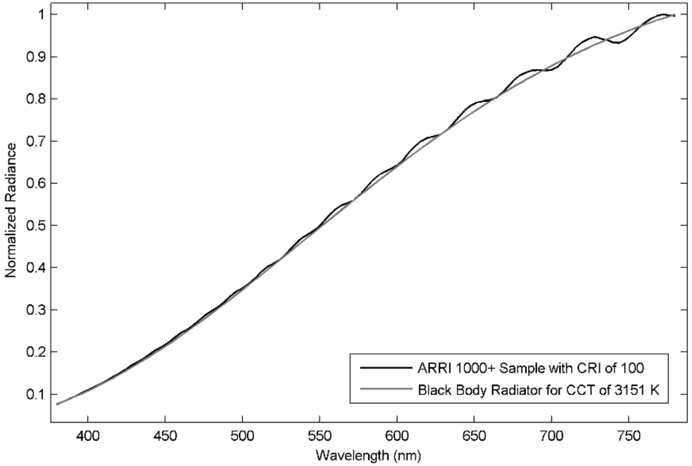
- The white target we used is made of polytetrafluoroethylene (Zenith-Polymer by SphereOptics).

- The spectrometer is a PhotoResearch PR 650, which measures the radiance (W/(sr m^2 nm)).

- All measurements have been performed 15-30 min after the lighting was switched on at a temperature of 23°C and approximately 30% relative humidity.

Results – Tungsten Lighting

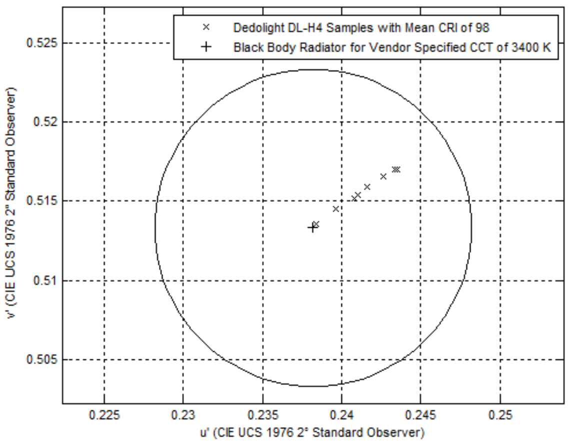




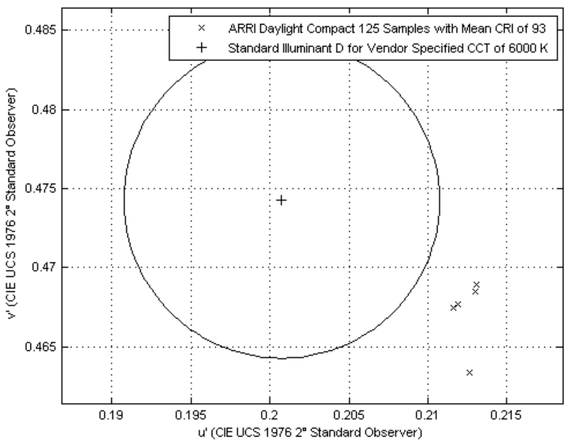
- Left Figure shows two ARRI 650+ spectral radiances, in which one light L1 is well adjusted (L1 Flood, L1 Spot) and the other one L2 is maladjusted (L2 Flood, L2 Spot)
- Right Figure shows the normalized radiance and CRI of one ARRI 1000+ sample at spot position and the ideal black-body radiation emitter for the correlated color temperature.
- 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.

Measured Lighting
– Colourimetrical Evaluation Samples

Tungsten sample nearly the vendor specified CCT and high CRI

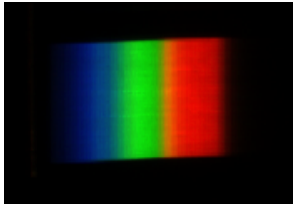


HMI sample different to the vendor specified CCT but acceptable CRI



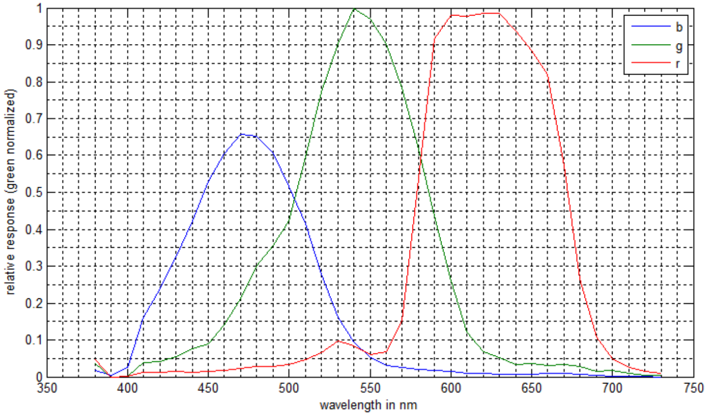
Estimating the Camera Spectral Response

- sample for Point Grey FL2-03S2C/Sensor Sony ICX424AQ



Uncorrected image data
(Tungsten illumination)

Correction



Better Matching for Mixed Scene Illumination - mean improvement dE2000 = 0.4326

	L ref	a ref	b ref	L CCT	a CCT	b CCT	L spec	a spec	b spec	delta E2000 CCT	delta E2000 spec	delta E2000 spec - delta E2000 CCT
Dark Skin	38,7891	13,6767	14,6252	44,6495	10,7372	24,4429	44,5838	11,3059	23,4907	9,2103	8,5124	-0,6979
Light Skin	66,4704	17,9886	17,993	69,2233	22,0956	24,3577	69,174	22,9684	23,3627	4,0496	3,8654	-0,1842
Blue Sky	50,4838	-4,5642	-22,3913	50,8693	-1,578	-12,0116	50,9836	-2,0351	-11,3448	6,4666	6,5637	0,0971
Foliage	43,6591	-13,2978	22,071	44,9181	-12,5097	30,7283	44,8142	-12,6436	30,0317	4,644	4,275	-0,369
Blue Flower	55,7685	8,8466	-24,7499	55,5171	10,4198	-10,9327	55,6361	10,3423	-10,4132	9,9356	10,2283	0,2927
Bluish Green	71,2449	-33,2517	-0,1144	67,7462	-27,9551	5,0559	67,7468	-29,038	5,5711	5,0689	5,0907	0,0218
Orange	63,1589	35,5501	58,2304	67,8831	30,7485	68,0008	67,7229	32,2745	63,2454	6,7567	4,9876	-1,7691
Purplish Blue	40,6006	9,7521	-44,6314	41,5802	12,1385	-33,1247	41,8836	11,4764	-31,9238	7,6664	7,9362	0,2698
Moderate Red	52,038	48,0623	17,0177	57,1472	49,8208	25,5208	57,1176	51,4082	23,6643	6,5455	5,8312	-0,7143
Purple	30,7886	21,1482	-20,1511	35,2438	21,2237	-4,7427	35,3211	21,6097	-4,6546	9,9935	10,1108	0,1173
Yellow Green	73,0224	-23,4496	57,3502	70,8651	-22,0098	58,9242	70,6763	-22,2352	57,2762	1,9457	1,8777	-0,068
Orange Yellow	72,5084	19,5791	68,5521	72,1755	14,687	82,7277	71,9754	15,844	77,068	5,5249	3,8369	-1,688
Blue	29,1588	14,862	-50,4544	31,9061	13,2074	-37,0715	32,2658	12,3742	-35,7605	6,3063	6,6286	0,3223
Green	55,595	-38,0357	31,8261	56,7699	-35,1443	32,1102	56,6461	-36,1678	31,89	1,6459	1,2413	-0,4046
Red	42,6542	54,4244	28,8612	50,5843	54,0174	32,768	50,5354	55,7661	30,0657	7,9722	7,6622	-0,31
Yellow	82,9003	4,035	80,4953	82,169	1,9805	88,251	81,939	2,8011	83,3486	2,1318	1,1745	-0,9573
Magenta	52,348	50,0692	-13,8997	55,9163	55,1049	1,8303	56,0003	56,4129	1,1852	8,3899	8,226	-0,1639
Cyan	51,1473	-28,3133	-28,1318	48,5025	-16,6815	-23,5462	48,6933	-17,9362	-22,4078	6,1798	5,5817	-0,5981
White D=0.05	97,2463	-0,4982	2,4467	96,1835	0,0724	16,3213	96,1634	0,113	16,1916	9,8402	9,7742	-0,066
Gray D=0.23	81,8288	-0,6631	0,2855	81,0291	0,8508	12,169	81,0218	0,8791	12,1148	9,5632	9,5374	-0,0258
Gray D=0.44	67,009	-0,5497	0,0022	67,0185	-1,1144	10,6048	67,0099	-1,1462	10,5794	8,5885	8,5731	-0,0154
Gray D=0.7	51,2538	-0,6592	-0,1322	51,2538	0,5143	7,4105	51,2538	0,5143	7,4105	6,7067	6,7067	0
Gray D=1.05	36,1846	-0,5542	-0,49	37,7639	0,1515	7,9109	37,754	0,1762	7,8437	7,414	7,3691	-0,0449
Black D=1.5	21,0479	0,0231	-0,386	24,2865	-0,4044	4,3826	24,2862	-0,4282	4,3952	4,9995	5,0122	0,0127

Results – Influence of Lense Transmittance