In Situ Measured Spectral Radiation of Natural Objects

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Abstract

The only commonly known source for some in situ measured spectral radiances is ISO 17321-1 [1]. It describes the principle of how the color characterization of a digital camera works and provides spectral radiances for 14 common objects.

This paper summarizes the results of a project that was started to collect several hundred measurements of all different kinds of objects under various illuminations keeping in mind typical scenes and objects that people take photographs of. In many cases the spectral radiation of objects is not only that of the reflected light. Sometimes the light coming form objects like leaves for example is a mixture of the reflected and the transmitted light. In other cases inter reflections between the objects modify the spectral radiance in scenes and some objects like the human skin appears totally different in real live compared to the skin tones of a reflective color target.

The collected data can be used as a scientific data basis for different studies related to natural objects. But the main reason to collect the data was to provide training data for the color characterization of digital cameras. Future work will show whether a carefully collected subset of the database is sufficient to create an ideal matrix or look up table for a digital camera but for the time being all app. 2500 measurements are available and used to calculate camera matrices.

Introduction

As is widely known digital cameras require a color characterization transform to provide correct scene referred images as described in ISO 22028-1 [2]. Most cameras use a 3x3 color matrix to convert the sensor RGB values into values that try to represent the scene colorimetry. The easiest way to calculate the correction matrix is to use the spectral distributions of typical known light sources and the spectral reflection of some known objects. Based on this data the product with the measured spectral sensitivities of the camera leads to the camera's RGB output values. At the same time using the color matching functions allows to calculate the XYZ values for these objects. Having both the camera RGB and the XYZ values the color correction transform that produces the least error can be calculated.

Standard light sources in combination with a reflective target are often used to calculate the matrix. But is that the best way? Do standard illuminants and pigmented papers really represent natural objects? We know they don't. But there is no database available that can be used as training data for "the best color transform" and that represents real objects under various natural conditions. All databases that are available measured "dead" objects using artificial light sources. This paper describes the collection of a database of real objects measured under real light sources and shows a couple of examples how to use this data and the differences compared to a simple reflective target.

Measurements

To gather the data a Photo Research PR650 portable spot spectroradiometer was used. This radiometer provides the spectral radiances for the visual spectrum between 380 to 780 nm in 4nm increments. In order to provide a reference for the lighting situation a 10 x 10 cm spectralon plate was used as a white reference and placed in the scenes in a way that its reflection provides a good approximation of what the operator thought to be the adapted white for the scene. In addition a photograph was taken of most of the scenes to identify the measured objects and is provided with the measurements. In some of them the white tile is visible and shows the typical way it was used. The areas that were measured are indicated using the measurement IDs.

Figure 1: *The upper image shows a typical measurement setup to measure skin tones and the lower picture shows a an example for the presentation of the results.*

Data Preparation

The resulting database contains the measured spectral radiances of the various objects, the related adapted white measurement, the white tile corrected measurement, and for most of the measurements an image of the measured object. The measurements are scaled to 5nm increments. Each object is characterized with a measurement ID and the data contains, a descriptive object type and subtype, a number for the related image, and the measurement data itself.

Examples

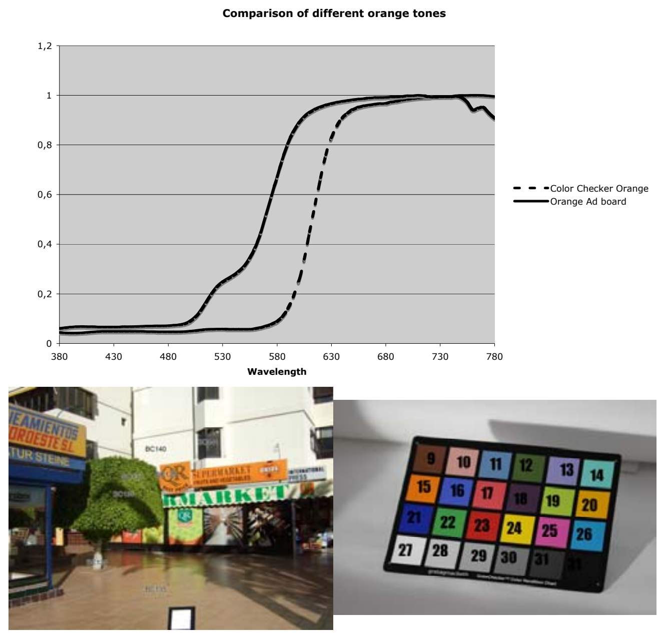

Figure 2: *A comparison of two orange colors. The Patch of the color checker (Measurement ID 15) and the orange advertising board of the shop (ID bc139).*

Real world colors vs. Color Charts

Although one may assume that the available color targets represent the real world colors, it is obvious that a reflective target is not capable of doing that. Even though the colors of a color checker in figure 3 appear to span a wide color space a few of the randomly selected colors from the real world measurements are far outside the gamut of the color checker. One can not even be displayed in the 3D plot created by a typical software because the L* value reaches 102 meaning the brightness was higher than that of the diffuse white which often is the case for single objects in photographic scenes.

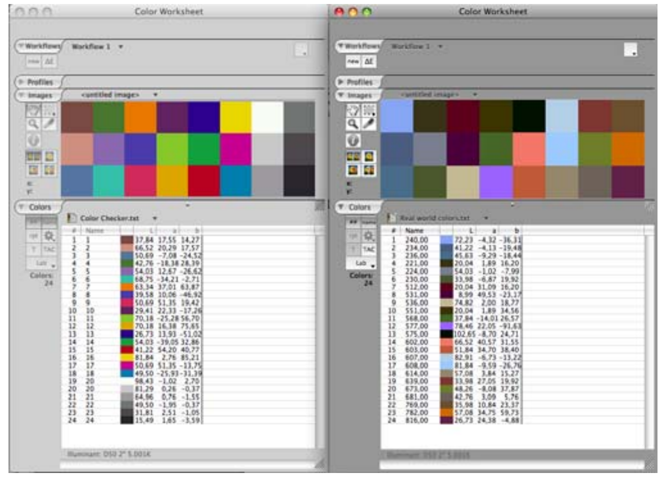

Figure 3: *On the left are the well-known x-rite color checker patches. On the right are some randomly selected measured real world colors.*

Figure 4: *The bright green in the center of the palm tree is brighter than the diffuse white in the lower foreground of the picture.*

variations when skin tones are corrected based on the spectral distribution of a patch.

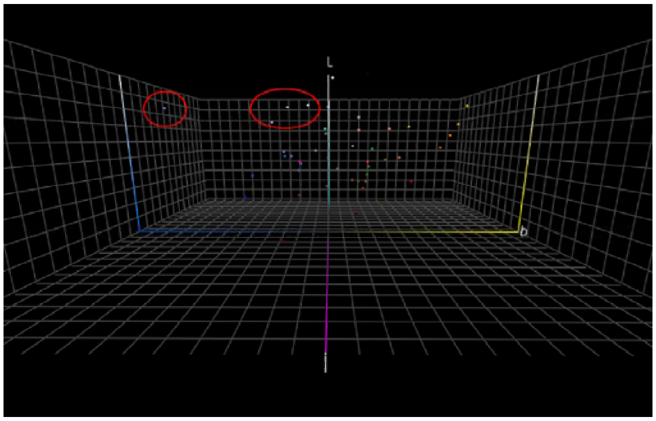

Figure 5: *The marked real world colors in the image are far outside of the gamut of the color checker.*

The bright, high-saturated blue sky in the same figure (4th color lower row on the right part of figure 3) turns purple as the same color does in many cameras. It is far outside the gamut of surface colors but it occurs quite often in real images and the color matrix needs to handle this color in the right way.

The bright blues as well as the dark reds are also not present in the color chart. The Color Checker SG addresses these colors but it is not capable of creating the high-saturated bright blue tones.

Does the green of the CC color patches really look like green grass?

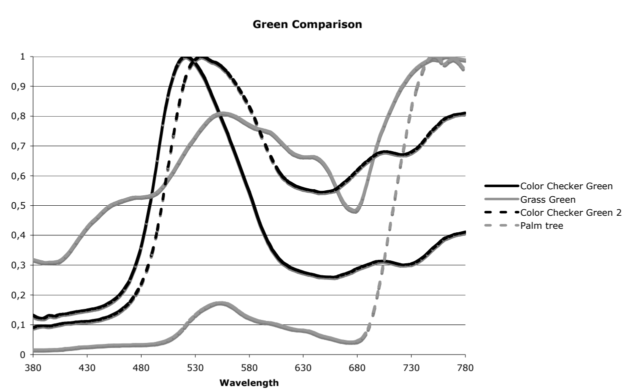

Figure 6: *The green tones of the color checker compared to the real green of grass or a palm tree.*

As can be seen from figure 6 the green of natural objects is completely different than the two green color patches of the color checker. On the one hand the red and IR reflection is much higher due to the reflectance of the chlorophyll. On the other hand the spectral reflection of natural green is much broader than that of the pigment paper colors.

We get the same kind of variation when real skin tones are compared to skin tone patches (see figure 8). This can lead to variations when skin tones are corrected based on the spectral distribution of a patch.

Skin Tones

Skin tones are very important in digital photography since about 80 % of all pictures taken with cameras contain one or more persons [3].

ISO 17321 only provides two samples of Caucasian skin tones. The spectral reflectance of Asian and African skin however is different and even among the Caucasian skin tones there is a variety of differences as our evaluation shows.

For the color characterization of a camera the absolute radiance values are important as well as the spectral distribution. For other applications the relative spectral distribution may be the most important thing. To show the usability we have processed the data and normalized it to the max value of each measurement. The three graphs for the different skin tones (Figure 8 to 10) show these comparisons. The Caucasian skin shows an interesting behavior with its low reflectance around 550 nm. We can see that Asian skin tones are not that much different from the Caucasian skin but the drop in reflectance in the 520 to 590 nm area is not as strong which makes the Asian skin look slightly more yellow. Caucasian 4 and the Asian Baby are known to have a sensitive skin with a bright skin tone. It is interesting to see the drop in reflectance below 400nm indicating a high absorbance level for blue and the near UV. This may be of interest from a medical point of view although it requires more investigation. But the data required may already be in the database.

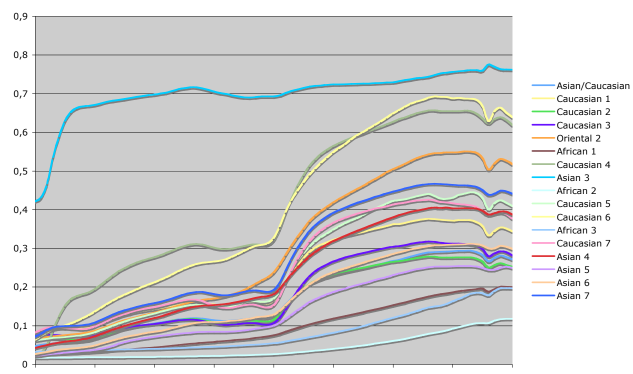

Figure 7*: The comparison of a variety of skin-tones as white tile corrected spectral radiances.*

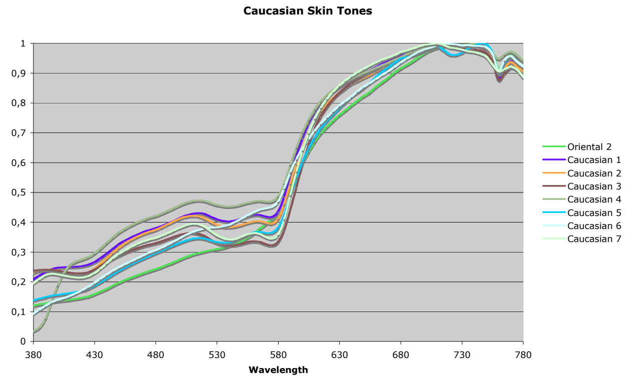

***Figure 8:** The Caucasian skin tones normalized to the maximum value for each measurement. The two skin tone patches of the color checker added for comparison.*

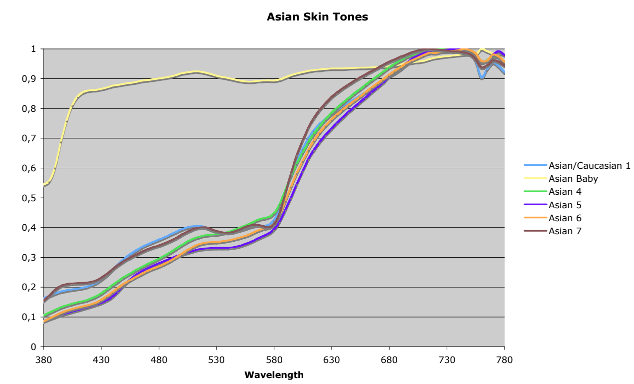

***Figure 9:** The relative values for the Asian skin requires some more evaluation that is currently in progress and will be available for the final paper. The change in skin tone for a girl that seemed to be an Asian/Caucasian mix is interesting to see.*

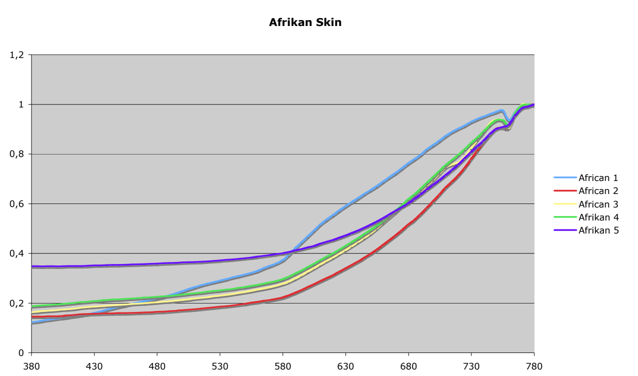

***Figure 10**: The African Skin is smoother in its spectral reflection besides the lower reflection level in general.*

Objects that emit radiation

For objects that emit radiation we get in trouble with conventional colorimetry since we do not have a white anymore that we can refer to. In this case we can only use the spectral distribution, as it is, calculate XYZ values and normalize to Y. If we calculate the L*a*b* values for the XYZ combination and refer that to D50 and the 2° observer we receive the following table:

	X	Y	Z	L*	a*	b*
green	37,896	100	8,965	100	-133,73	104,52
blue	269,296	100	1402,516	100	204,18	-314,47
red	196,720	100	6,980	100	134,19	112,16
yellow	95,235	100	1,787	100	-2,03	144,22

But this does not make any sense because the observer is not adapted to D50 when he views these objects. Still they play an important part in photography and need to be taken into account for camera characterization.

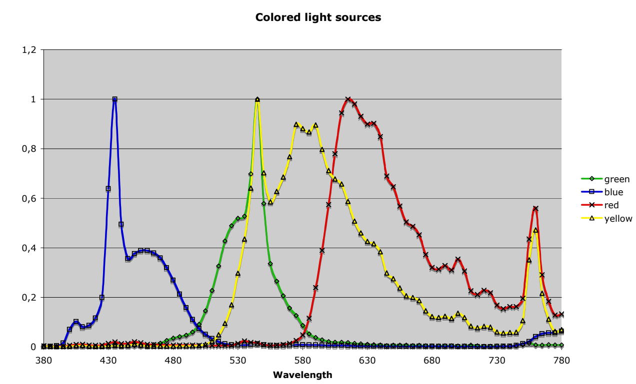

***Figure 11:** The spectral distribution of colored light sources.*

***Figure 12:** Examples for colored light sources in images.*

Transmission and reflection

When the spectral radiance of objects is measured it is important to know the adapted white that we get from the white tile but it is also important to know the characteristics of the illumination. To provide an example we have measured objects under natural daylight. One time the sky provided a diffuse illumination and the other the same objects were measured under direct sunlight. The white tile was used in both cases to correct the data for the adapted white and the spectral data was referenced to the max wavelength to avoid any remaining influence from the amount of light.

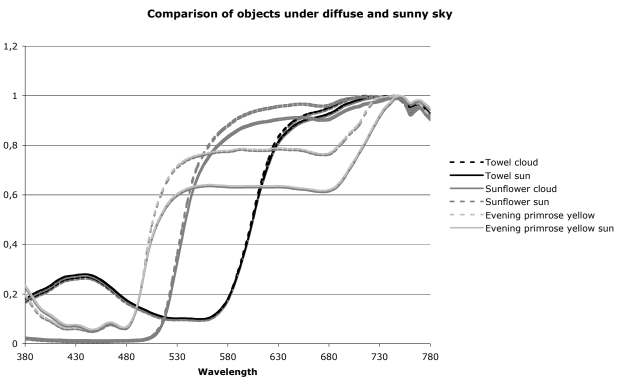

Figure 13: The data shows that the relative spectral radiance changes with the lighting conditions.

The towel that was not transparent shows nearly no variation of the spectral radiances after the white tile correction. The more transparent the object is the higher the difference between the two measurements. The yellow evening primrose has a huge amount of transmitted light when illuminated by direct sunlight.

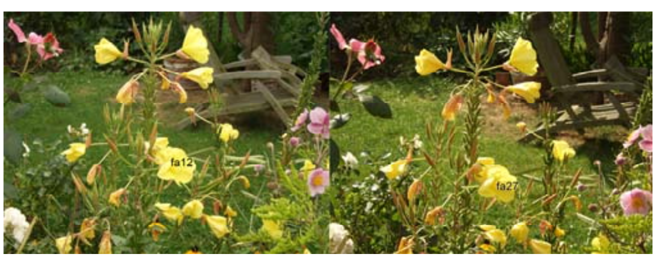

Figure 14: *The evening primrose on the left with diffuse illumination and on the right under direct sunlight*

Figure 15: *One of the other scenes under diffuse and direct illumination.*

Summary

The comparison of color patches with colors of real objects has shown that the difference in the spectral distribution is significant. We have also demonstrated that reflective targets are not able to span the whole color space a camera needs to be able to capture. This leads to the conclusion that color targets are not the ideal basis for a camera color correction matrix. Therefore a database of in situ measured spectral radiances is necessary to improve the quality of digital cameras. This database needs to consist of measurements taken at different illuminations of a huge variety of objects. Future work will show if it is possible to derive a limited but well selected dataset for the determination of high quality matrices for digital cameras.

Besides this photographic application that was the reason for building the database there may be other areas where spectral radiations of natural objects are of interest such as medicine, pharmacology, agriculture, biology, geology etc.

Acknowledgements

I would like to thank Kevin Matherson from HP who made these measurements possible and Eric Walowit for his advice in the planning of the measurements.

References

[1] ISO 17321-1 Graphic technology and photography — Colour characterization of digital still cameras (DSCs) — Part 1: Stimuli, metrology, and test procedures.

[2] ISO 22028-1 Photography and graphic technology — Extended colour encodings for digital image storage, manipulation and interchange — Part 1: Architecture and requirements.

[3] Wueller Dietmar, Statistic analysis of millions of digital photos, Proceedings SPIE/IS&T Electronic Imaging Conference 2008, Digital Photography IV, Volume 6187.

Author Biography

Dietmar Wueller studied photographic sciences from 1987 to 1992 at the University of Applied Sciences Cologne (Germany). Since 1997 Dietmar Wueller runs an independent test lab for digital cameras and scanners that has also developed to one of the leading suppliers for test equipment for digital image capture devices. He became the German representative for ISO TC42 WG18 in summer 2000, is a member of the board of the European Color Initiative, and besides running his company he works on his phd thesis on noise measurements at Leeds University.