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J.J. McCann, V. Vonikakis, and A. Rizzi,
" Scene Content", Chapter 8 in
HDR Scene Capture and Appearance,
SPIE Spotlight Tutorial, Chapters 1-15, 2018
http://spie.org/Publications/Book/2315540?&origin_id=x109925&SSO=1

This is a quotation from and SPIE Spotlight Tutorial.

It describes an experiment that used a lightbox with variable light emission in a scene photographed in RAW format. Increased light emission cause increased glare, that affected the data recorded throughout the entire scene.

8 Scene content controls appearance

In previous chapters we have seen high-range and low-glare scenes, as well as low-range and high-glare scenes. In this Chapter we measure the effects of glare on those darker segments by using a variable range scene. We begin with a low-dynamic range scene with a ColorChecker. It is a part of the constant darkest segment of the scene We add to that a small, variable luminance lightbox. By increasing the lightbox luminance we increase dynamic range, and glare. By making photographs of the changing scene with constant exposure, we monitor the effects of glare on the darkest scene segments. The procedure provides a tool for measuring glare in response to dynamic range.

8.1 Adding glare to the grayscale

The greater the dynamic range of the scene in front of the camera lens, the greater the influence of glare on the darkest scene segments. The following experiments used a scene that contained a bright LED lightbox with controls that adjusted its luminance. When the lightbox was turned off, its diffuser measured 15.6 cd/m^2 in ambient light. The small lightbox was placed close to the camera; it had a black baffle behind it so that no light from it fell directly on the ColorChecker. Increasing the output of the lightbox increased the range of the scene, and added a small amount of ambient light to the room.

The purpose of the experiment is to measure camera response with variable ranges of the scenes. There were five LibRAW photographs, each made with the same exposure. The lightbox had a different luminance in each photograph (lightbox off-15.6; 469; 1,980; 3.950; 19,200 cd/m^2). Three of the five photographs are shown in Figure 8.1.

Figure 8.1 illustrates three of the five photographs using jpeg images. 8.1(left) shows the light box off; (right) shows maximum luminance. The lowest scene luminance was??

Figure 8.2 plots the linear average LibRAW camera digits vs. reflectance of the ColorChecker grayscale.

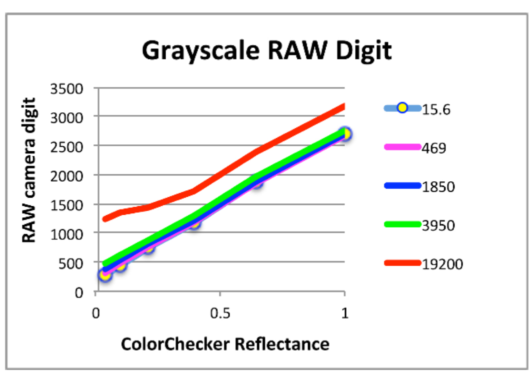


Figure 8.2 plots RAWG camera digits vs. reflectance of ColorChecker grayscale squares. The five lightbox luminances are 15.6, 469, 1,850, 3,950, 19,200 cd/m^2.

Figure 8.2 plots RAWG camera digits vs. reflectance of the grayscale squares for the five photographs with variable lightbox luminances. The graph shows increasing camera response from the increase in range and optical glare. Because of the linear plot, the highest lightbox output shows the most obvious increment of stray light.

The principle of *Multiple Exposures* in HDR is to use calibrated exposure times to derive the camera response function (CRF). An alternative technique is to us camera digit vs. known reflectance values to make the CRF. Using gratscale reflectances and RAWG digits we can fit the inverse CRF. The best data for measuring the camera sensor's response is RAWG data from lightbox off. That data gives us the camera inverse function:

$$-CRF_{15.6} = (0.0004*RAWG)-0.0847$$

[equation 8.1]

Figure 8.3 plots the actual reflectance value (dashed line); the fit using 15.6 lightbox off data (yellow circles). The lowest level lightbox, 469 cd.m^2, showed slightly higher digits for the lowest reflectances.

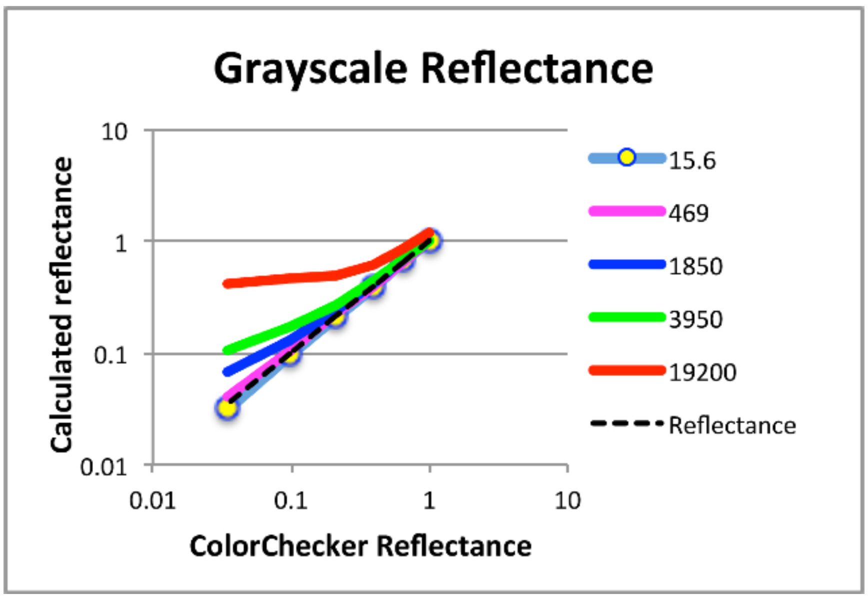


Figure 8.3 is a log-log plot of calculated reflectance using Equation 8.1 vs. ColorChecker reflectance.

As dynamic range and optical glare increase, the 469 lightbox luminance plot has higher digits that fit by the inverse CRF (Magenta line). With each increase in lightbox luminance, the fit of the inverse function gets worse.

Figure 8.3 (log-log plot) demonstrates three important facts:

- First, all increments of lightbox-on added glare to the darker image segments.
- Second, increase in dynamic range causes an increase in glare. Glare is a spatial convolution of the scene luminance array. Since it is a joint property of the scene and the camera optics, the inverse CRF cannot correct for it. Each of the five different photographs generates a different inverse CRF.
- Third, the use of camera digits in arithmetic calculations, such as reflectance, requires great precision. Ratios of two numbers are very sensitive to the accuracy of those numbers. As an example, reflectance has been suggested as the signature of an object's surface. That hypothesis uses scene digits to identify surfaces from

estimating reflectances. The data in Figure 8.3 shows that constant reflectances in uniform illumination have glare distorted variability. Glare makes calculated camera-based reflectances unreliable as an object's signature.

8.2 Adding glare to colors

As illustrated in Figure 5.1, most digital cameras use a colored mosaic filter to give each sensor pixel either R, or G, or B spectral sensitivity. Since 1861 when James Clerk Maxwell's first demonstration of color photography, R, G, B separation images have been the predominant starting point for color reproduction. Maxwell used three projectors to optically superimpose three separate films, each with a separate colored filter. Additive mosaic films in the early twentieth century made single digital exposures possible. Subtractive imaging (using yellow, magenta, and cyan dyes) dominated the second half of that century. Today, the dominant display technology has returned to additive RGB light-emitting displays.[i]

8.2.1 Chroma enhancement

Chroma enhancement was first described by Albert[ii] in 1889. Maxwell's color separations are a technique to capture separate portions of the visible spectrum and reproduce them. Practical limitations imposed by19th century dyes made pure spectral separations impossible. Poor spectral separation results in dull unsaturated color reproductions. Albert's idea was to enhance colors by combining a positive image of one color separation with negative images of the others.

Color enhancement is a powerful tool in making attractive photographs. It enhances chroma, while holding hue and lightness constant. In ordinary digital images it takes the form:

$$R_{out} = +aR_{in} - bG_{in} - cB_{in}$$
$$G_{out} = -dR_{in} + eG_{in} - fB_{in}$$
$$B_{out} = -gR_{in} - gG_{in} + iB_{in}$$

[Equations 8.2]

where $R_{out}, G_{out}, B_{out}$ are the output enhanced color values; R_{in}, G_{in}, B_{in} are input camera sensor response values, and coefficients [$a,b,c, \ldots i$] are tuned to optimize chroma for the camera's individual spectral sensitivity properties. By subtracting a fraction of the other color channels responses, each individual channel is enhanced.

Color enhancement is found in all standard digital camera images. It stretches chroma values while holding hue and lightness constant. Standard camera firmware introduces chroma enhancement. Such camera Rout, Gout, Bout values are not an accurate record of scene radiances. Figure 5.2 compares chroma-enhanced Jpeg and normalized RAW color photographs from the same camera. Algorithms that attempt to measure color information from standard photographs can be severely limited by nonlinear R, G, B data.

Multiple Exposures, and their inverse CRF, do not have a mechanism to identify the nine coefficients, and invert the chroma enhancement process. In standard photographs, the data available to measure CRF contains all camera enhancements. Further, in standard camera images, the CRF is nonlinear. That means the combination of CRF and color enhancements are a nonlinear transformation of scene radiances. This is the reason we have adopted LibRAW data extraction in this study. We used LibRAW algorithms to acquire camera data before chroma enhancements take place.

8.2.2 Chromaticity and glare

Chromaticity is a two dimensional illustration of hue and chroma (color saturation). *Camera Chromaticity* is the geometric projection of a three-dimensional color solid onto a plane defined by the RGB components. Position in the plane, defined by r and g are calculated as:

[Equations 8.3]

$$r = R_{out} / (R_{out} + G_{out} + B_{out})$$
$$g = G_{out} / (R_{out} + G_{out} + B_{out})$$

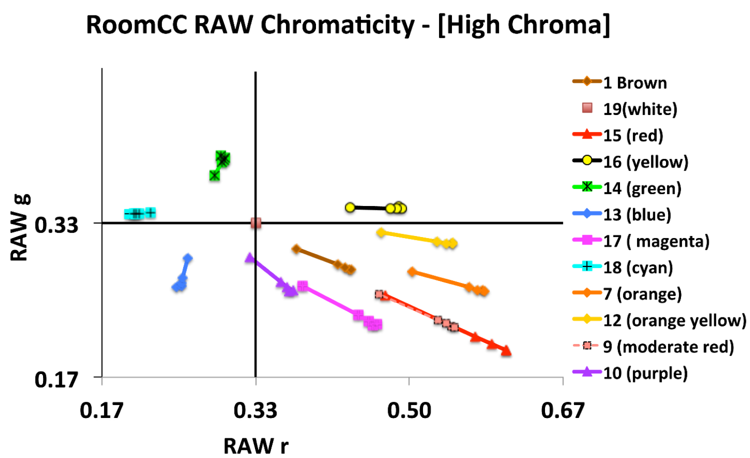
where R, G, B are the digital color values from the camera image. (Camera Chromaticity should not be confused with colorimetric chromaticities (x, y) that represent camera-independent transforms of color-matching functions (CIE X,Y, Z)[iii].

Chromaticity ignores lightness because it compresses the 3-D color space onto a plane. All chromatic samples (white, gray, black) plot in the center of a chromaticity plot. Hues project from the achromatic center, each with a characteristic hue angle. Chroma is plotted as distance from the center along the hue angle.

Chromaticity is a tool used frequently in Computer Vision Color Constancy algorithms.[iv] Camera chromaticity values are specific to the camera system and file format. (Camera chromaticity is distinctly different from CIE Colorimetric chromaticities in that it has has no color matching properties.) Chromaticity is a ratio involving a sum. That requires strict linearity of input information.

Figure 8.4 plots the RAW chromaticities of colored squares in the five photographs with variable range. For clarity the graph plots 12 of the 18 ColorChecker squares with high chroma.

Figure 8.4 plots the RAW camera chromaticities of 12 high-chroma square in the five photograph with



variable range. The grayscale squares superimpose at 0.33, 0.33. The 15.6 (lightbox-off) chromaticities are the most distant from the achromatic value. The effect of increased glare is a decrease in chroma.

Using RAW data from the five photographs described above in Section 8.1, the R, G, B camera data is linear. RAW data is extracted before chroma enhancements. Chromaticity plots are normalized to color balance the photographs. In Figure 8.4, the RAWR data was normalized to the $RAWR_{(white)}$; RAWG normalized to $RAWG_{(white)}$; RAWB normalized to $RAWB_{(white)}$.

The chromaticity results (Figure 8.4) show that the five photographs render different camera chromaticities. Changing the range, and consequential glare, gave different chromaticity values for all 12 high-chroma colored squares. The data provides evidence that glare from the content of scenes will modify camera chromaticity values to the extent they introduce errors in color computer imaging algorithms.

Figure 8.5 shows the R, G, B RAW color separation photographs of the ColorChecker portion of the 19,200 cd/m^2 image. The red, green, and blue asterisks identify the darkest reflectances in each color separation. These squares have the largest glare distortion.

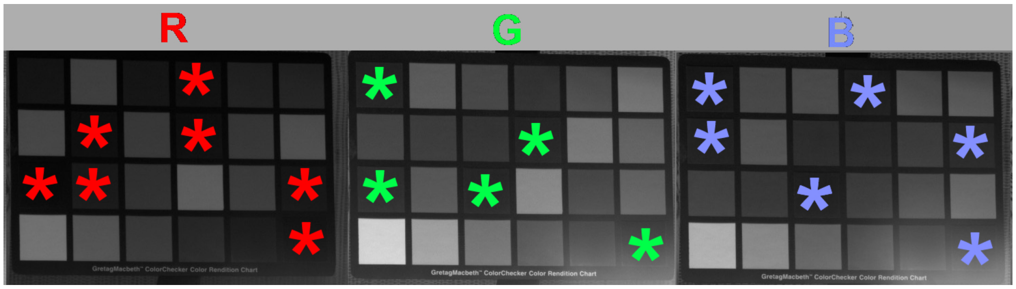


Figure 8.5 shows RAW color separations of the 19,200 cd/m^2 image.

The asterisks identify the darkest reflectances in each separation. Black is the only square the has low reflectance in all three separations. High-chroma colors show individual color changes from glare because of the different distortions in each separation. Color distortions vary with spectral-spatial light distribution of the scene in front of the camera.

Summary

Increasing range causes an increase in glare in a scene's darkest areas. Glare adversely affects algorithms that estimate achromatic reflectances from camera data, and attempts to measure the chromaticity of illumination, and distorts the use of chromaticity to identify the hue and chroma of colored surfaces.

Color enhancements, used in almost all standard digital cameras, introduce chromaticity nonlinearities that cannot be removed by inverse CRF algorithms.

- Glare adds unwanted light to photographs of gray, dark gray, and black ColorChecker squares. That unwanted increase in camera digit value makes estimates of object reflectance unreliable.
- Experiments using LibRAW data extraction, with no chroma enhancements, show that glare influences camera chromaticities.
- Glare adds unwanted light to photographs of colored squares. That unwanted increase in camera digit value makes estimates of the color balance of scene illumination, and the spectral signature of objects unreliable.

It is important that we replace simplifying assumptions about camera properties with measurements of actual performance.

References

i McCann, J. J , "Color Theory and Color Imaging Systems: Past, Present and Future", J. Imaging. Sci. and Technol., 42, 70-78 1998.<http://mccannimaging.com/Retinex/Publications_files/1998%20JISTf.pdf>

ii Albert, E., German Patent 101379 (1889).

iii Wyszecki G & Stiles W *Color Science: Concepts and Methods, Quantitative Data and Formula* , 2nd ed ,: John Wiley & Sons , Inc, New York, 156-173 (1982).

iv iv Gevers, T., Arjan Gijsenij, T., Joost van de Weijer, J., Geusebroek, J. M., Color in Computer Vision, Wiley, Chichester, (2011).

Recommended reading

Chroma Enhancement

Friedman, J. S., "Chapter 19, Masking", in *History of Color Photography*, The American Photo Publishing Co, Boston, 273-295 (1944).

Spencer, D. A., "Chapter XIV Masking and Colour Correction", in *Colour Photography in Practice*, The Focal Press, London, 297-328, (1966).

Yule, J. A. C, "Colour Reproduction in the Graphic Arts," in *Neblette's Handbook of Photography and Reprography*, 7th ed., Van Nostrand Reinhold, New York, 466-480, (1977).