This is a preprint of 9015-31 paper in SPIE/IS&T Electronic Imaging Meeting, San Jose,
Feb, 2014

ColorChecker® at the beach:
Dangers of sunburn and glare

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Abstract

In High-Dynamic-Range (HDR) imaging, optical veiling glare sets the limits of accurate scene information recorded by a camera. But, what happens at the beach? Here we have a Low-Dynamic-Range (LDR) scene with maximal glare. Can we calibrate a camera at the beach and not be burnt? We know that we need sunscreen and sunglasses, but what about our cameras? The effect of veiling glare is scene-dependent. When we compare RAW camera digits with spotmeter measurements we find significant differences. As well, these differences vary, depending on where we aim the camera. When we calibrate our camera at the beach we get data that is valid for only that part of that scene. Camera veiling glare is an issue in LDR scenes in uniform illumination with a shaded lens.

Keywords: scene capture, glare, dynamic range, computer vision color constancy

1. INTRODUCTION

Reproduction of High-Dynamic-Range (HDR) scenes has its roots in Renaissance chiaroscuro painting [1: chapter 4]. Recent digital image algorithms have fused multiple exposures to extend the dynamic range of scene rendition [2]. However, the actual range of accurate radiance values extracted from camera images is limited by scene-dependent optical veiling glare. Cameras can accurately record more than a four log-unit range of radiance of small spots in a very dark surround, such as stars at night. However, in a white surround such as a sandy beach, the range is reduced to less than two log units because of optical veiling glare [1: chapter 11].

Veiling glare introduces the scene-dependent limits to camera radiance measurement in HDR scenes. Extended range scenes are easily found in everyday experience because of nonuniform illumination, i.e. sun and shade. What is the Low-Dynamic-Range (LDR) limit? In perfectly uniform illumination, can a camera accurately capture the dynamic range of the calibration ColorChecker® test target?

2. PREFERRED RENDERING AND RAW FORMAT

Ordinary camera images, that look good, have undergone a significant amount of signal processing to make a preferred image. Digital cameras are good at controlling exposure, color balance, and color saturation to render very attractive pictures [3].

Some of us, however, want to use cameras in a manner that they were not designed for! We want to use the cameras to accurately record scene radiances. We want to use camera digit arrays, conveniently saved in digital files, to measure light at millions of scene pixels. The problem is that the carefully engineered camera systems were not designed to accurately record radiance, they were designed to create the best scene rendition. Although the sensors at the start of the rendition process count photons, there are many nonlinear camera operations designed to make the best rendition at the end of the system. For example, cameras use large amounts of color masking that increase chroma of all non-achromatic stimuli. Color masking is a chromatic amplification that distorts a color sample's reflectance chromaticities [4].

2.1 RAW and RAW* images

RAW format images were introduced to allow photographers more control. They provide the photographer the ability to control in software the many automatic image processing operations usually performed in camera firmware. The RAW format stores images that are much closer to linear records of the light falling on the camera sensor. There is no international standard for RAW. Each company provides a different software package that gives the photographer more control, but that does not mean that all RAW images are linear records of scene radiances.

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A better scene-capture approach is to use RAW image data that has been verified to be linearly proportional to scene radiances. Funt and Shi [5] used DCRAW freeware library to read camera RAW and convert it to a black and white image that is as close as possible to the sensor's response. It is a single image that contains the different RGB sensor responses to the Bayer pattern mosaic.

We calibrated our digital cameras using multiple exposures of the ColorChecker®. We measured the camera digits from the same image areas from each exposure. In the camera's linear-response range the difference in camera digits corresponded to the change in exposure. In the regions near the maximum and minimum digit values, the camera responses were no longer linear. The difference in camera digits no longer corresponded to the change in exposure. The nonlinear values are called "outliers".

The experiments used the LibRaw (2013) Image Decoder Library [6], which is built on DCRAW. More specifically, we used the “unprocessed” function of LibRaw which outputs the unprocessed data of the RAW file, without applying any processing such as demosaicing, denoising, white balance, gamma modification, enhancement, compression, or min/max normalization. This results in an image with visible Bayer pattern and unnormalized R, G and B responses. For this reason, we used separate calibration RGB LUTs to scale the linear sensor responses, and attain the equal RGB output response for achromatic patches. We refer to the output of this process as RAW*, described in McCann and Vonikakis [3]. All images referred to as RAW* have no "outlier" pixels, because we experimentally verified linearity.

2.2 Camera calibration - Extracting linear data

If we review the calibration procedures:

- RAW extracting libraries such as DCRAW or LibRaw provide the closest access to the achromatic sensor response as filtered by Bayer pattern color array.
- Between saturation at very high exposures, and the noise pedestal for low exposures, the camera's response is linear.
- The RAW R, G, B responses have different slopes depending on the spectral content of the light.
- The linear RAW R,G,B responses for chromaticity measurements are necessary, but not sufficient. The RGB response functions need to be color balanced, so that achromatic scene objects have equal RAW R, G, B digits. (RAW* calibration procedure - [3])
- Any camera digits in each of the RAW R,G,B images that reach min or max linear limits are "outliers" and they reduce the number of pixels that are usable camera chromaticity responses.

Under the above conditions with DCRAW/LibRaw data camera chromaticities are proportional to scene chromaticities and can be used for calculating the average illumination and performing image analysis. For the low-range ColorChecker® scene, there is a limited range of exposures in which the entire test target is free of outliers in R, G, and B records in daylight.

3. CAMERA GLARE

The remaining task is to test for veiling glare in the camera. McCann and Rizzi (1: Chapter 11) measured the dynamic range of cameras, as limited by scene content. They used an achromatic transparent target with a dynamic range of 18,619: 1. They found that glare from the entire scene added light to the actual scene radiances.

The effect of glare cannot be removed because it is the sum of all the very small amounts of scattered light from every pixel. The amount of glare from each distant pixel depends on that pixel's intensity and the distance between scattering pixel and receiving pixel. The camera green digit G_c is the sum of scene radiance G_s and veiling glare v. It is the sum of glare from all other pixels and light from outside the camera sensor's field of view.

$$G_c = G_s + v$$

$$v = \sum_{1,1}^{x,y} f(G_s, d) + L$$

In these equations x is the maximum horizontal pixel location address, and y is the maximum vertical pixel location address. Typically the product of $x*y$ equals millions of pixels. Veiling glare is the scene radiance G_s convolved with the glare spread function (GSF) for every other scene pixel in the camera's field of view [7]. Glare is a function of the distance (d) between the location (x_i, y_i) of Gs. L represents the glare light that falls on the camera lens from light sources outside the camera's field of view. The forward calculation using all the accurate scene radiances and the camera's glare spread function can calculate the resulting image with glare, as long as we know all the scene radiances at each pixel without glare. Given the GSF we can calculate the image on the camera sensor.

The reverse process is not possible. If we need to calculate the accurate radiance G_s for a scene pixel from the camera radiance digits, we have to accurately calculate the values of millions of separate $v_{x,y}$ contributions from every pixel, and the glare L from light falling on the lens from outside the camera's field of view. No one has shown a real solution to this problem. Optical experts agree that this inverse calculation is not possible, as stated explicitly in the ISO standard for measuring veiling glare (ISO 9358, 1994 [8]).

4. LDR TARGET ON A BEACH

The "Dark Side of Color" question is: "Can we accurately record the dynamic range of a ColorChecker® in uniform illumination using a camera? The extreme case is when the ColorChecker® is sitting on a white sandy beach.

The following experiment measures the influence of veiling glare at the beach. Our experiment used the ColorChecker® achromatic papers that have a radiance range of only 29:1 in uniform illumination.

To illustrate the effect of scene content we made RAW* G images of four scenes with different scene content. In all cases the lens was shielded from the sun, and the camera pointed away from the sun. The pictures were made with a Canon D60 camera with subtracted dark pedestal. We used a Canon EF 50 mm F/1.8 II primary lens having only five optical elements, so as to minimize glare.

Figure 1 shows the scenes:

- 1441: ColorChecker® inside an automobile shaded by trees
- 1456: Closeup of the ColorChecker® on a beach
- 1459: Same scene - greater distance (ColorChecker® is 1/9th the image area)
- 1481: Same scene taken much further back (ColorChecker® is 1/144th the image area).

Figure 1: The scenes: ColorChecker® on black, and on the a beach at different distances.

Control photo 1441 (Figure 1, left), taken inside an automobile on a dark background shows good correlation for five achromatic squares. The camera reflectance estimate for the black square is 1.8 times actual; namely the camera estimate is 6.2 % while the meter read 3.4%. reflectance relative to the white square. In this case, the camera glare has elevated the black reflectance value by 0.255 log units.

The beach scenes (Figure 1; 1456, 1459, & 1481) showed larger errors for all squares, reaching 2.85 overestimate for black reflectance in Photo 1481. All the beach scenes show overestimates of the middle-gray square more than 1.25 times. The three beach-scene photographs have different fields of view in constant, uniform illumination. The constant reflectance ColorChecker® squares have different camera RAW* responses because of changes in veiling glare caused by different scene content.

The black line in Figure 2 plots the meter readings of the reflectance of the six achromatic squares along the bottom of the ColorChecker®. The horizontal axis is % maximum luminance read by a Konica Minolta C100 meter for those six squares. Our meter readings match the values reported by Pascal [9]. The vertical axis is the ratio of camera-estimated reflectance to actual reflectance. These estimates were made from RAW*G data known to be in the linear camera response region.

This simple experiment used: an LDR scene; in uniform illumination; no direct illuminant light hitting the lens, a lens with only 5 elements; and RAW* linear digits. Nevertheless, the veiling glare from a white sandy beach generated variable camera radiance measurements depending on image content. A beach scene has a distribution of image luminance values that are nearly all at the maximum luminance value, thus providing more scattered light in the camera's image plane. The ColorChecker® in a dark environment has less veiling glare and smaller errors from scene content.

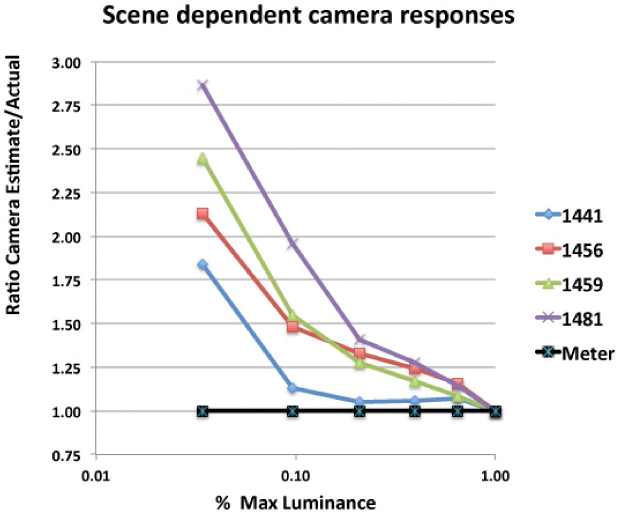

Figure 2. Ratio of camera estimate/actual vs. % max luminance.

Veiling glare has little effect on ordinary photography. They are anticipated and processed by the image rendering built into digital cameras. Human vision has variable neural contrast responses to retinal images modified by intraocular scatter [1: Chapters 14-19]. Human vision compensates for veiling glare.

Those of us who want to use camera digits for scientific calculations, such as computer modeling and computer vision, have a problem. It would be very useful for us to take a digital image and to use that array of data as the input to our algorithm research. The problem is that the camera digits do not represent the scene radiances. They represent scene radiance plus scene dependent veiling glare. Not all algorithms care about the capture of accurate scene radiances, however, some do. Computer vision color constancy is one example in which variable veiling glare from scene content can modify the prediction of an object's reflectance.

ACKNOWLEDGMENTS

These measurements were done in collaboration with Vassilios Vonikakis and Mary McCann.

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