Using a Spectral Source to Characterize a Digital Camera and Build an ACES Input Device Transform (Draft)

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Abstract

The movie industry is experiencing a fast transition from traditional film capture to digital capture. New digital cameras and new color workflows are introduced, reasserting the need for proper characterization methods.

While several methods exist, we propose a new method to determine the spectral sensitivity of digital cameras. This method involves a Programable Spectral Source, and consider the couple camera/lens as a recording device.

In this paper, we demonstrate the advantages that can be drawn from a programmable spectral source compared to a monochromator. Indeed, this device has a programable spectral bandwidth, can vary in terms of purity. The characterization is then used to build an Input Device Transform as proposed in the specifications of the ACES Academy of Motion Picture Arts and Sciences (AMPAS). The proposed protocol is simple, robust and automatic.

Introduction

Unlike photographic workflows, in which the photographer his the sole handler of his picture from shooting to shaping before diffusion, movies require teamwork partitioned between shooting and post-production. In photographic practice, the reduced number of images can even confuse camera calibration and artistic choices in the only color editing operation. Since the numerical values of the file are expressed in a recognized workspace, the issue of color management is shifted to the restitution of the image on different media (e.g. a print).

The movie industry is in a transition from traditional film capture to digital capture. In a fragmented workflow, involving several professions, directors of photography often know little about the digital image processing and color science. When shooting digital, they are worried of loosing their artistic influence during the shooting for the benefit of post-production. To help directors characterize the new digital cameras that can now be rented, we propose a new characterization method using a spectral source.

A practice of color management for the cinema that ensures consistency of visual perceptions throughout the chain has to be simple and robust. Therefore in this work, we adopt the logic of a workflow ACES [1] advocated by the Academy of Motion Picture Arts and Sciences (AMPAS). See Figure 1 We focus on the characterization of cameras, taking into account that in a movie shooting, cameras will be used with different pre-settings and with several different lenses. In this context, we propose to set an Input Device Transform (IDT) for each camera.

In the first section of this paper, we will review existing characterization approaches. In the second section, we will describe the proposed characterization setup and protocol. In the third section, we analyze the data to determine the characteristics of the camera. The fourth section will consists of a discussion of the experimental results and in the last section we will focus on building the Input Device Transform.

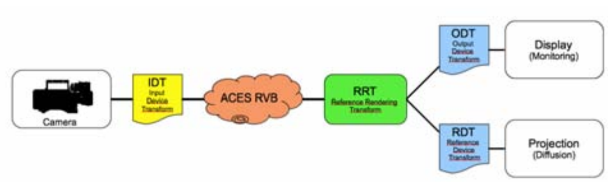

Figure 1. *Simplified diagram of the ACES based workflow proposed by the AMPAS.*

Target-based and Spectral sensitivity-based Methods

Two approaches are generally proposed: Target-based and Spectral sensitivity-based methods [2].

Figure 2. *Two generations of the test target X-Rite ColorChecker DC.*

The target-based methods consist of shooting a reference target and calculate a transform that best matches the colors expressed by the camera sensor and module treatment to the colors of the original scene. In practical terms, this approach leads to the design of a 3D LUT that establishes a network between the original colors (those of the charter ...) and those of the desired photographic copy. This method quickly shows its limits and the results depend on the choice of colors (including their method of manufacture, ie their spectral type) and the number of patches that make up the charter. Moreover, this approach underlies the need to reproduce the same color perception whereas L.A. Jones [3] demonstrated that to be subjectively satisfactory, an image was to present, to say the least, a distortion of reality in terms of values. Furthermore, the use of this method leads to mix the artistic rendering intentions with the need to objectively control colors in the production line of the image. On a more practical aspect, the method justifies that the procedure should be repeated as soon as lighting conditions change, and quickly shows its limits in terms of heterogeneous shootings and natural scenes which constitute the essence of cinema.

Spectral sensitivity-based methods are directly inspired by the conventional methods of sensitometry. This type of method has the advantage of providing objective data independently of subjective considerations that will be addressed later in the process of image processing. It is the method used in this work to determine the response curve of the camera (H&D vs OECF) and its spectral sensitivity curve. The latter is usually achieved using a monochromator placed in front of a tungsten lamp. In the context of photography, Poovi et al. [4] expressed that there was no significant difference between the two methods while stressing that this was the fact that they use lights in narrow bands. The results obtained with this method depend on the choice of reference colors and the number of patches.

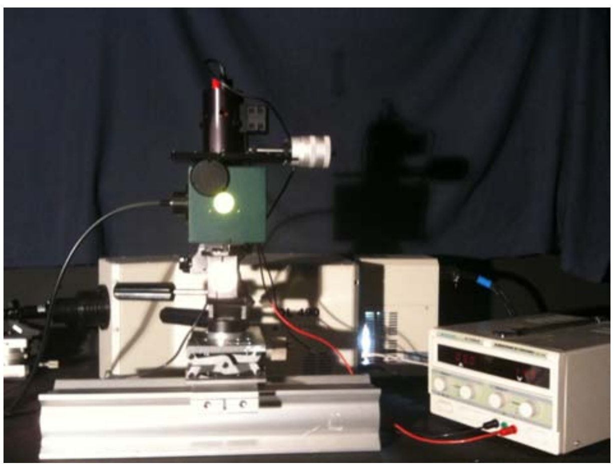

Figure 3. *Illuminant device consisting of different light sources mixed in an integrating sphere.*

Characterization in terms of spectral sensitivity for digital movie demands more precision in photography because successive shots and may originate from different cameras. It is essential to know the color analysis functions of the different cameras to match the rendered image between different shots. This way we can extract much more information: the color temperature of the device steady shooting, the response curve that allows us to express an index of sensitivity, noise and the useful range of the system. This information is useful both for the director of photography and for the design of an IDT to translate data from the camera into the encoding space ACES-RGB. Finally, we express the spectral sensitivity to determine the primary color analysis. We consider the contribution of the spectral transmittance of the lens and as corrective elements of the IDT generic.

Characterization Setup

One Camera Body, Several Lenses

The normal shooting situations are such that the equipment is leased, thus the same operator uses different cameras depending on the specifics needs of the shooting but also on the availability of equipment that day. A set of several lenses will be used during the shooting of a movie, yet the shooting conditions and artistic intentions of the director often lead to the selection of one main lens.

To account for these conditions, we systematically characterized a device consisting of the camera body and this main lens. In addition, each lens of the lens set will be characterized by its spectral transmission and the rate of flare that it brings in the system. So we can evaluate the impact of each lens on the quality of the system.

Spectral Source

The protocol we propose is based on a device consisting of different light sources mixed in an integrating sphere (See a photography of the device Figure 3). With this device, we can both recreate the different states of natural light and generate monochromatic lights. To achieve this, we mix a tungsten source, a source with deuterium and a Programmable Spectral Source. This source is the *OL-490 Agile Light Source*, based on a xenon arc lamp spatially dispersing its light with a grating. A chip DLP modulates each monochromatic lines programmatically. According to the light characteristics we want to extract, we will activate independently the sources in pre-determined sequences.

Compared to a monochromator, this device has a programable spectral bandwidth, can vary in terms of purity. Its spectrum is richer, mainly in the blue.

The camera is placed facing the source of diffuse light that emerges through a hole drilled in the center of a black card, in shooting conditions that correspond to the framing of tests usually performed in the camera rental facilities. The spectral distribution of the source is systematically measured and monitored using a spectroradiometer Konica Minolta CS-2000.

Measurement Protocol

One or more cameras will be measured. For a given camera: We first setup a heating time of 15 minutes. Then we start recording the different sequences with different white balances, exposition of a modulator target with different shutter speed. Evaluation of flare with main lens, using a specific test target. Note that for each cameras several tests at different point in time we be achieved, to evaluate reproducibility.

Balance Color Temperature Sensor

To evaluate the balance color temperature of the sensor, we place the camera before the broadcast source of our experimental setup and submit it to various simulated daylights (illuminant series D expressed as an increment Mired) as well as typical spectra of the sources used in shooting (HMI, Tungsten, LED, etc.). We consider that the color balance is achieved when the responses of channels Red and Blue are identical. We also assess the relative level of channel Green to determine if the images have a color cast and a possible bias on the Green / Magenta axis.

Opto-Electronic Conversion Function(OECF)

In the current protocol we use a sphere of enlightenment on which we place transparent targets. We tested models charters distributed in commerce and chosen for our experience, make our own patterns (In particular, the printing raster disturbs considerably the results.) We therefore used a range carbon as a modulator (traditional sensitometry) opaque black background so as to limit the flare. (See a photography of the device Figure 4).

Its contrast, slightly higher than 1:1000, is not yet sufficient to exceed the useful range of most sensors. This forces us to practice more exposures by varying the luminance of the source. The test is performed to balance color temperature sensor and the operation is repeated for each sensitivity index proposed by the manufacturer. This is an opportunity to observe whether or not this setting affects the pre-amplification of the sensor.

Once we have sufficient power in our spectral source, we would also use it to establish the OECF to automate the creation of light stimuli.

Figure 4. *Spherical transparency illuminator.*

Spectral Sensitivity

The camera is placed in front of the device spectral mixture. The source is calibrated in such a way as to generate no matter what the wavelength of the same radiance. It then generates three sequences at a rate of spectral stimuli per second by scanning the spectrum from 380 to 760 nm and varying the intensity, bandwidth and desaturation of the equi-energy white light. The first sequence is done with a pitch of 1 nm and the other with a pitch of 5 nm. To compare the contribution of the source spectral programmable to determine the spectral sensitivity of the cameras, we are to make the characterization with a monochromator coupled to a tungsten source. On the same couple camera / lens operation is repeated 3 times over time.(See Figure 6).

Influence of the Lens

When the camera is used with multiple lenses, we must determine the contribution of each in terms of color (spectral transmittance) and flare ”optical”. Thus we perform a flare test with the main lens mounted on the camera. Indeed, the flare can be envisaged as a result of the whole system of shooting and in particular related to the multiple reflections of light between the lens and sensor. A transmission pattern with a contrast of 1:1000 has been constituted for the occasion. We consider the flare as uniform across the fields registered. The value of the flare factor (FF) is the ratio on the Subject contrast and Image contrast. Is determined after survey of numerical values which are compared with those recorded with the OECF curve obtained under conditions of minimal flare. The sensor is used as a measure of image contrast. This value will serve as a reference when making the IDT.

However, for each of the lenses we evaluate the importance of this phenomenon by placing them in front of a sphere of diffusion in which was placed a light trap. The influence of each of the lens flare is seen in relative terms compared with the main objective. The results of these measures will be closer to the results observed for the target “main” placed in position, i.e. mounted on the camera. Finally we determine the spectral transmission curve of each of the lenses by placing them between two integrating spheres. One source for widespread and the other to capture the radiation transmitted by the lens.

Protocol Limitations

It’s all about qualifying the cameras in terms of color rendering which implicitly rendered values. For completeness we should also study the characteristics of records of details (resolution, modulation transfer function) which also influence the capacity of restitution of contrasts. We assume here as a possible extension of this protocol. Yet each camera is different from its treatment methods, coding and registration of images. Access to raw sensor data is in most cases impossible. In this case it is yet to linearize the signal before processing the data which can be tricky and a source of uncertainty in the absence of manufacturer information.

Data Analysis

In each of our product tests with the cameras, we need to read numeric values stored in the files and link them with the photometric measurements. We set the numerical value as the average value of a patch of 300x300 pixels taken from the center of each image. For statistical analysis, we determined that we needed to have, according to the cameras, a number between 10 and 30 images of the same stimulus to reproduce our calculations. Thereafter, each numerical value is expressed as the result of this statistical measure.

With this measuring principle we determine for each of the conditions of shooting color temperature balance and the torque factor flare camera / main lens, opto-electronic conversion function and finally the spectral sensitivity. There is always variance in order to assess the level of noise necessary to characterize the useful range and a reasonable range of sensitivity indices. Several methods have been proposed to determine the primary analysis of the device from the color matching function of digital camera. To choose the one that we retain in our protocols, we apply three methods with three cameras and submit the images to a panel of viewers in a psychophysical experiment. We of course use the method proposed by the Academy, which takes into account the 24 patches of the ColorChecker. On the other hand, we chose to use a simplified approach, based solely on correspondence neutral tones complemented with a sensitivity metamerism index. The contributions of each of the lenses in terms of flare and color cast are estimated by measurements spectro-radiometric and are directly usable.

Construction of the Input Device Transform

The Input Device Transform will be built from the previous results and expressed in Color Transformation Language (CTL). Will be successively considered the law of tonal gradation so as to express a linear encoding, flare correction, the possible dominant color of the lens resulted in terms of gain, the conversion matrix RGB_{camera} to ACES-RGB and adjustment function to match the tone curve of the Reference Input Capture Device (RICD).

Discussion

The objectives of this work are manifold: In one hand, to demonstrate the value of a programmable spectral source in this context and propose a specific protocol and robust that can be automated. It was designed to be simplified as and progress. On the other hand, to verify if it is essential that each camera is coupled with its own IDT, or if a generic IDT provided by the manufacturer, which by definition does not take into account the lens, is sufficient to match the flow of different images.

At this stage it is difficult to conclude on the robustness of the protocol because only three different cameras have been characterized (RED ONE Mysterum X, Arri D21 and Arri Alexa) with the same lenses. Three new tests will take place in a week with two Sony cameras known to behave differently (F-35 and SRW-9000PL) and another Arri Alexa. The next couple of months will be an opportunity to repeat the tests on different camera models but also on the cameras of the same model but have been used differently. The variety of tests should allow us to objectively classify the influence of individual characteristics studied in the rendering.

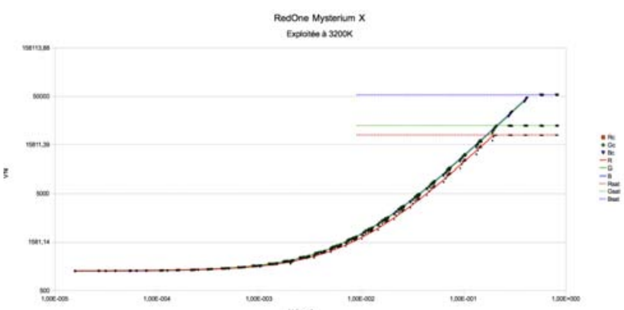

Figure 5. This response curve of the RedOne Mysterium X camera is expressed logarithmically. It indicates a perfectly linear response to the brightness of the scene without any knee point. The extent of the useful dynamic range is slightly greater than 1:100. Saturation levels are very different for each of the RGB channels, which imposes virtually using the camera to a high level of sensitivity since we do not use it to its chromatic balance.

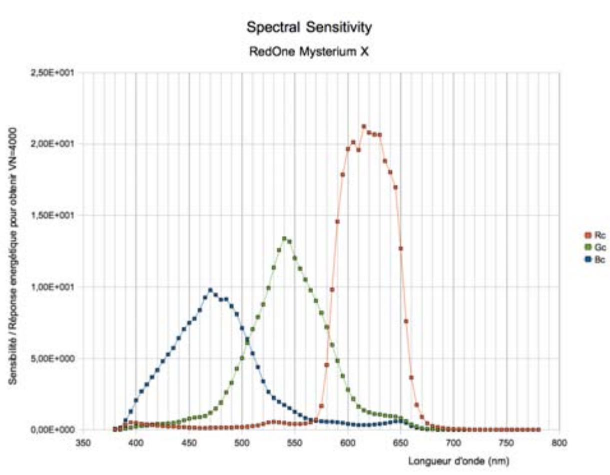

Figure 6. Spectral sensitivity of the camera RedOne Mysterium X.

Future Work

Several aspects of this work are ongoing:

• Multiply the number of camera tests and repeat the procedure in time with the same couple camera / lens.

• Specify, on the basis of a larger corpus, the minimum number of images and size of patches to be considered for the measurement of numerical values.

• Evaluate and document the acceptable noise level for an image. For the moment we have arbitrarily fixed the SNR at 20, referring to the ISO 12232:1998 [6] and placing ourselves between the two levels of quality. There is every reason to believe that the assessment is very different in photography and moving image. The issue is important because it affects both the practical characteristics (dynamic range, sensitivity) as measures of numerical value. This point alone justifies a psychophysical study.

• Measure and characterize a representative number of lenses including lenses developed specifically for digital cameras in order to appreciate their diversity in terms of dominant color and flare. In this work we opted for Zeiss lenses to PL mount because it was guaranteed to test all the camera with the same lens.

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Author Biography

Alain Sarlat graduated from Ecole Nationale Supérieure Louis Lumière (ENSLL) in 1994 (Paris, France), major in photography. He is currently lecturing Sensitometry and Colorimetry, in the sections Photography and Movie of the ENSLL. He is also coordinator of the major Psychophysics of the image. Since January 2008, he his the project manager and scientific leader of the ENSLL team Consistency and continuity of visual perception within the project HD3D.