Considerations in the Design of a New Printing Density Metric and Encoding for Contemporary Motion Picture Applications

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Abstract

The Science and Technology Council of the Academy of Motion Picture Arts & Sciences is developing an architecture for digital motion picture mastering applications known as the Image Interchange Framework. As part of the architecture, a new optical printing density metric called Academy Printing Density (APD) and a new density encoding specification known as Academy Density Exchange Encoding (ADX) have been proposed. This paper will outline the need for a new printing density metric and encoding and detail many of the considerations in their design.

Introduction

Academy Printing Density (APD) specifies a printing density definition appropriate for use with motion picture negative and internegative films and serves as the basis for the density encoding method of Academy Density Exchange Encoding (ADX). The spectral responsivities that define APD, known as Π_{APD}, are based on the spectral sensitivities of contemporary motion picture print films such as those of the Kodak Vision family, of the Fujifilm Eterna family, and of Fujifilm F-CP. Its definition is also based on the spectral power distribution of a Bell & Howell Model C printer lamp house with dichroic filters and the spectral transmission of an Eastman Kodak Wratten Filter No. 2B. As such, the spectral responsivities Π_{APD} are capable of interpreting the optical densities of motion picture color negative and internegative films as the film manufacturers intended those densities be interpreted.

Academy Density Exchange Encoding is the common densitometric encoding of scanned motion picture color negative film images used within the Academy's Image Interchange Framework (IIF). The purpose of the spectral responsivities Π_{APD} is to provide a well-documented metric for measuring color negative film density values, allowing the unambiguous encoding of those densities in ADX. The encoding of density images in ADX within the Academy Image Interchange Framework allows for the development and use of a universal (i.e. non-stock-specific) transform to convert images encoded in ADX into ACES images.

The spectral responsivities Π_{APD} also serve as a reference against which scanning device behaviors can be compared within the Image Interchange Framework. When a scanning device with spectral responsivities other than Π_{APD} is used to scan a motion picture color negative or internegative film, a stock-specific Input Device Transform (IDT) converts the resulting scanner density values into the APD density values a scanning device with the Π_{APD} spectral responsivities would have produced from that same color negative film. APD and ADX are important components of IIF, which allow for the input and output of images on motion picture negative and internegative films. This paper will detail many of the considerations in their design.

Background

The spectral responsivities associated with any printing density metric are the product of the spectral power distribution of a printer light source, the spectral transmission, reflection, and absorbance of the optical components of the printer, and the spectral sensitivities of the print medium onto which the sample is to be printed.[1] The spectral product for any densitometric specification, film scanner, or densitometer may be denoted as:

$$\Pi = S(\lambda)s(\lambda) \tag{1}$$

where:

$S(\lambda)$ is the relative spectral power distribution of the influx.

$s(\lambda)$ is the relative spectral sensitivity of the receiver, which includes the photodetector and all intervening components between it and the plane of the sample to be measured.

As noted earlier, the subscript Π_{APD} is used to denote the spectral product representing the spectral responsivities used to calculate APD. Π_{APD_R}, Π_{APD_G}, and Π_{APD_B} are used to denote the spectral responsivities of the red, green, and blue components of APD respectively.

The subscript S_{APD} is used to denote the relative spectral power distribution of the influx spectrum used in the calculation of the spectral product Π_{APD}. S_{APD} includes the effect of the light source spectral power distribution and the spectral transmission, reflection, absorbance of the optical components of a Bell & Howell Model C printer lamp house, and the spectral transmission of an Eastman Kodak Wratten Filter No. 2B. S_{APD} is illustrated in Figure 1.

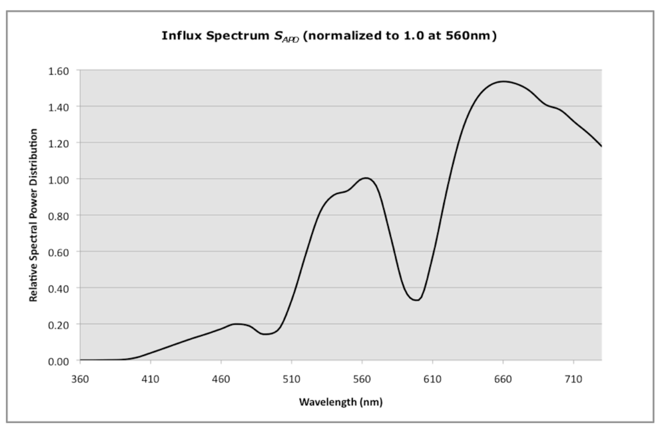


Figure 1. *- Influx Spectrum* S_{APD}

The spectral sensitivities of the print medium are representative of the spectral sensitivities of contemporary motion picture print films such as those of the Kodak Vision family, of the Fujifilm Eterna family, and of Fujifilm F-CP. The spectral responsivities Π_{APD}, are illustrated in Figure 2.

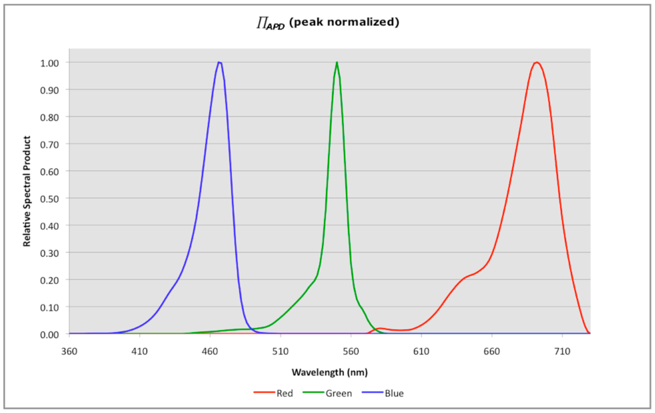


Figure. 2 *-The spectral responsivities* Π_{APD}

Existing Printing Density Standards

Π_{APD} has been determined to be the appropriate spectral responsivities for scanning devices digitizing motion picture color negative and internegative film imagery. Its greater currency and unambiguous specification make Π_{APD} a better set of spectral responsivities for a scanning device than the spectral responsivities given in SMPTE RP-180-1999 (Archived 2006)[2][3] or the unpublished spectral responsivities that were the basis of Eastman Kodak Cineon Printing Density (CPD). Both the RP-180-1999 and CPD Printing Density specifications are based on the spectral sensitivities of print stocks that are no longer manufactured. In addition, the spectral responsivities that serve as the basis for CPD were never fully specified.

APD is directly compatible with contemporary color negative and internegative film stocks, as well as any legacy motion picture color negative and internegative film stocks capable of being printed onto contemporary print films with reasonable results. When appropriately encoded, APD is also compatible with scan-only color negative films, such as Kodak Vision2 HD Color Scan Film (Kodak 5299), even though color negative film stocks of this type are not intended to be directly printable. APD is not appropriate for scanning of color print film material.

Reference Measurement Device

To completely specify a density metric it is necessary to also specify the conditions in which the density measurements shall be made.[4] The Academy specification "Academy Density Exchange Encoding (ADX) and the Spectral Responsivities Defining Academy Printing Density (APD)" defines the spectral responsivities, measurement geometry, and sample conditions for a reference measurement device.

The specification states that the reference measurement device shall have spectral responsivities equal to the spectral responsivities Π_{APD}, the device geometry shall conform to the ISO standard diffuse transmission density specification found in ISO 5-2:2001(E), and films to be measured shall be at 23°C ± 2°C (73.4°F ± 3.6°F) and 50% (±5%) relative humidity also consistent with the sample conditions specification for density measurements found in ISO 5-3:1995(E). [4]

These specifications are intended to eliminate ambiguity in the determination of the APD values of a film sample and should not be misconstrued to be specifications for conditions under which films must be scanned.

Calculation of APD Values

There are two methods for determining the APD values of color negative and internegative films; spectral calculation and conversion from other density metric values.

The spectral calculation of Academy Printing Density values requires the measurement of the spectral transmission of the color negative or internegative film using a spectral measurement device. A densitometer with spectral responsivities equal to the spectral responsivities of Π_{APD} could measure APD values directly, however, no such densitometer currently exists.

Measured film transmission spectra can be converted into APD values using the following equations:

$$APD_R = -\log_{10}\left(\int_{360}^{730} T(\lambda)\bar{r}(\lambda)\,d\lambda\right)$$

$$APD_G = -\log_{10}\left(\int_{360}^{730} T(\lambda)\bar{g}(\lambda)\,d\lambda\right)$$

$$APD_B = -\log_{10}\left(\int_{360}^{730} T(\lambda)\bar{b}(\lambda)\,d\lambda\right)$$

where: (2)

$\bar{r}(\lambda), \bar{g}(\lambda)$, and $\bar{b}(\lambda)$ are Π_{APD_R}, Π_{APD_G}, and Π_{APD_B} normalized such that

$$\int_{360}^{730} \Pi_{APD\_R}(\lambda)\,d\lambda = \int_{360}^{730} \Pi_{APD\_G}(\lambda)\,d\lambda = \int_{360}^{730} \Pi_{APD\_B}(\lambda)\,d\lambda = 1$$

and

$T(\lambda)$ is the spectral transmission of the color negative film or internegative film, or $10^{-density(\lambda)}$

Conversions between other density metric values (i.e. Status M density, scanner density, etc.) and APD values are also possible. These transformations are product specific and a separate transformation needs to be determined for each color negative and internegative film product. ISO Status M to APD 3x3 matrix conversion transforms and associated residual errors for a variety of commonly used motion picture color negative and internegative films are provided in the Academy specification. The provided transforms can be particularly useful in process control efforts. However, while the average residual errors for equivalent neutral densities are sufficiently small for that purpose it should be noted that residual errors for densities representing highly saturated colors could be quite large.

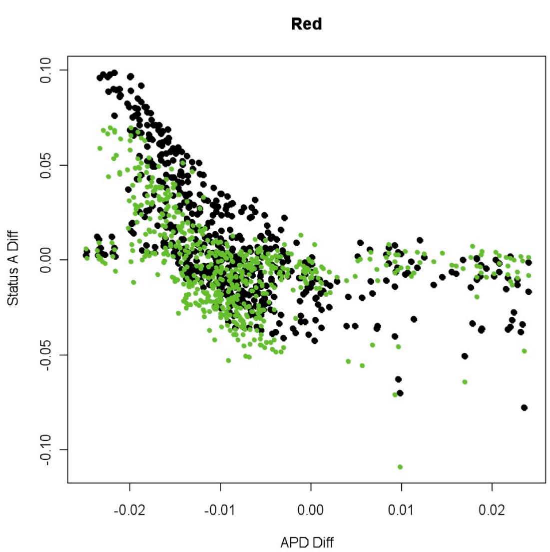
For that reason when the native scanner spectral responsivities are exactly known, the residual errors may be reduced by the use of a more complex mathematical transformation. Compared to a 3x3 matrix, a polynomial conversion transform may substantially reduce the residual error associated with the conversion between density metrics. Assuming the use of a transform with an appropriate number and distribution of nodes, the use of a stock-specific 3D LUT, particularly when used in conjunction with one or more 1D shaper LUTs, could nearly eliminate the residual errors associated with the transform.

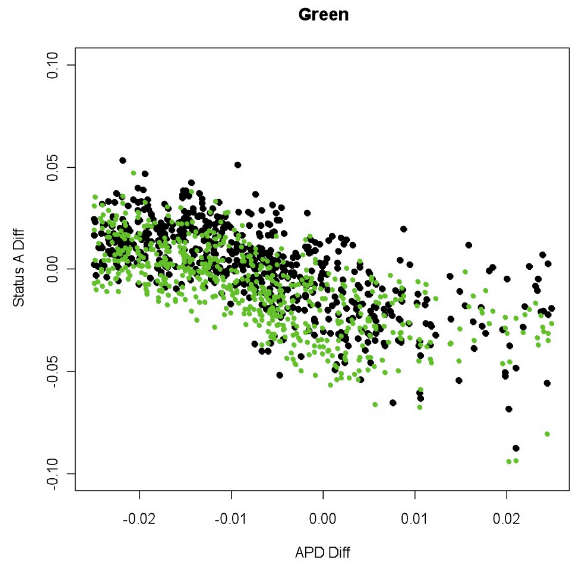
APD Metric Validation

If ADP were a valid measure of film printing density, it would be expected that different negative and internegative stocks measured to have the same Academy Printing Densities - but different Status M densities - would produce identical prints. To test this hypothesis a set of test colors including a 6^3 cube was recorded on camera negative and internegative films with an ArriLaser film recorder. The spectral transmission of each film was measured and both APD and Status M were calculated.

Patches with sufficiently similar APD values on each film were identified. Due to differences in minimum base density, processing variations, and film recorder calibration limitations not all colors were reproduced with sufficient accuracy to be used for the test. Only color patches with an APD difference smaller than or equal to 0.025 in each of the three layers were used for the APD validation test.

Each of the negatives was printed onto Eastman Kodak 2383 and Fujifilm 3510 print films. The prints were measured and the resulting Status A densities compared. Overall, the limit of 0.025 difference in APD density results in 99% of all samples having matching print densities with errors less than 0.1, 0.04, and 0.07 in cyan, magenta, and yellow, respectively. A later test comparing the spectral transmission of the print films confirmed the results and APD was deemed to be a significantly more accurate measure of printing density than Status M. A comparison of the errors for each layer can be seen in Figure 3.





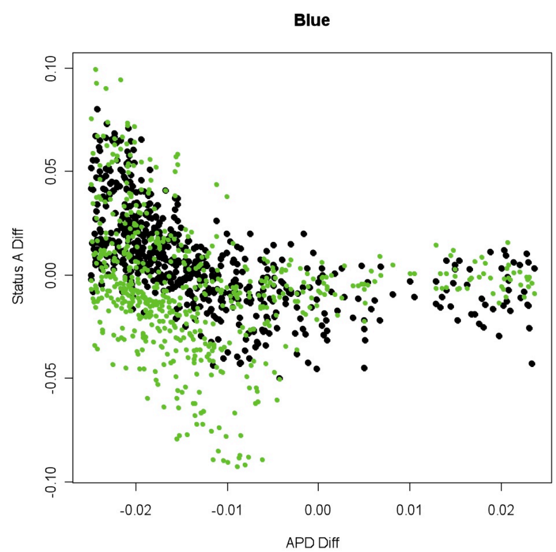


Figure 3 *- Comparison of APD and Status A Errors for each layer. Black represents the results on Kodak 2383. Green represents the results on Fujifilm 3510.*

ADX Encoding Method

ADX values encode image data as the Academy Printing Density values of a color negative film designed to be printed on Kodak Vision family, Fujifilm Eterna family, and Fujifilm F-CP color print films.

Most color negative and internegative films require no transformation in order to be compatible with the ADX encoding method, because most color negative and internegative films can be printed onto contemporary color print films with reasonable results. Color interpositive films are also compatible with the ADX encoding method as they are part of the negative reproduction chain.

Some film stocks, such as scan-only color negative film (e.g. Kodak 5299) and color print films, were not designed to be printed onto color print films. Printing a scan-only negative or color print film onto a contemporary color print film is not likely to yield a result that would be considered 'good-looking'. Scanned density values from these materials require additional transformation in order to achieve compatibility with the ADX encoding method. A custom conversion from scanner density values to ADX must be designed for materials that were not designed to be printed onto color print films.

ADX Encoding Metrics

The Academy Density Exchange Encoding (ADX) encodes densitometric images within the Image Interchange Framework. The ADX equations convert APD values to digital code values as 10-bit or 16-bit integer color components.

The encoding data metric for the ADX is based on D_{min} offset Academy Printing Density values. In many cases the D_{min} offset adjustment is accomplished during the setup of the scanning device. In the equations given below APD_{R_Dmin}, APD_{G_Dmin}, and APD_{B_Dmin} represent the red, green, and blue APD values respectively of the assumed or measured D_{min} of the sample.

Two component value encodings are provided. ADX_{16} in which the R, G, and B printing density values are each stored as 16-bit unsigned integers, and ADX_{10} in which the R, G and B printing density values are each stored as 10-bit unsigned integers.

The exposure of a spectrally nonselective (i.e. neutral color) object by a source for which the film has been balanced, followed by nominal laboratory processing, would ideally produce a negative having equal Red, Green and Blue printing densities. This ideal behavior, historically present in systems that comply with the silver criterion, is not a characteristic of contemporary motion picture negative films stocks. Encoding gain factors of 1.04, 0.96 and 0.99 in the encoding equations below attempt to produce equality in ADX values for the abovementioned exposure. These gain factors were computed as a weighted average of gain factors for commonly used motion picture films, and will produce ADX values whose corresponding Status M densities are compatible with the capabilities of modern film recorders recording onto intermediate stocks.

The Figure 4 shows the distribution of the measured APD values for a grey scale recorded on 17 negative and internegative films. The negative and internegative films were processed in a manner that represents typical process and latent image keeping variations.

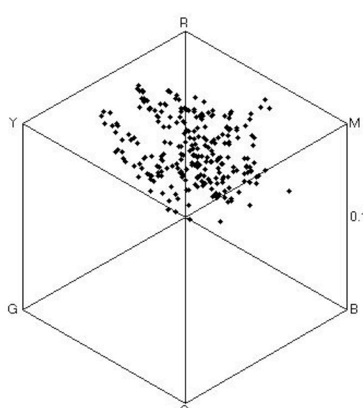


Figure 4 – APD values of 17 films.

The Figure 5 shows the same distribution of the measured APD values with the encoding gains of 1.04, 0.96, and 0.99 applied. The APD values, on average, are more neutral with the encoding gains applied than without.

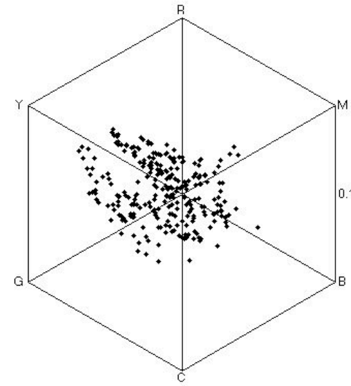


Figure 5 – APD values of 17 films with encoding gain factor applied.

16-bit Component Value Encoding Metric – ADX_{16}

ADX_{16} code values are 16-bit unsigned integer values. The value range for ADX_{16} is [0, 65535]. An encoding gain of 8000 code values allows for the encoding of a density range of 8.191875 with the density difference between adjacent code values equal to 0.000125. An encoding offset of 1520 code values allows for a density range of 0.190000 below the measured D_{min} to be encoded.

ADX_{16} code values are transformed from APD values using the following equations.

$$
\begin{aligned}
ADX_{16\_R} &= \mathrm{INT}\left[1.04 \times \left(APD_{R} - APD_{R\_Dmin}\right) \times 8000 + 1520\right] \\
ADX_{16\_G} &= \mathrm{INT}\left[0.96 \times \left(APD_{G} - APD_{G\_Dmin}\right) \times 8000 + 1520\right] \\
ADX_{16\_B} &= \mathrm{INT}\left[0.99 \times \left(APD_{B} - APD_{B\_Dmin}\right) \times 8000 + 1520\right]
\end{aligned}
\quad (3)
$$

The INT operator returns the value of 0 for fractional parts in the range of 0 to .4999… and +1 for fractional parts in the range .5 to .9999…, i.e. it rounds up fractions equal to or greater than 0.5.

It should be noted that the quantity ($APD - APD_{Dmin}$) may produce negative values as the D_{min} value of each color layer can vary throughout a scanned roll. The offset quantity, 1520, provides a target value for the scanned D_{min}, and allows 'footroom' so that densities lower than APD_{Dmi} will be encoded.

10-bit Component Value Encoding Metric – ADX_{10}

The 10-bit component value encoding metric is specified to provide compatibility with existing hardware and file format specifications. Some modern motion picture color negative and internegative film products are capable of producing density ranges that exceed the density range capable of being encoded by the 10-bit component value encoding metric. For this reason, whenever possible the 16-bit component value encoding metric should be used.

ADX_{10} code values are 10-bit unsigned integer values. The value range for ADX_{10} is [0, 1023]. An encoding gain of 500 code values allows for the encoding of a density range of 2.046000 with the density difference between adjacent code values equal to

0.002000. An encoding offset of 95 code values allows for a density range of 0.190000 below the measured D_{min} to be encoded.

ADX_{10} code values are transformed from APD values using the following equations.

$$
\begin{aligned}
ADX_{10\_R} &= \mathrm{INT}\left[1.04 \times \left(APD_R - APD_{R\_Dmin}\right) \times 500 + 95\right] \\
ADX_{10\_G} &= \mathrm{INT}\left[0.96 \times \left(APD_G - APD_{G\_Dmin}\right) \times 500 + 95\right] \\
ADX_{10\_B} &= \mathrm{INT}\left[0.99 \times \left(APD_B - APD_{B\_Dmin}\right) \times 500 + 95\right]
\end{aligned} \quad (4)
$$

Converting between the 16-bit and 10-bit Component Value Encoding Metrics

The 16-bit Component Value Encoding Metric (i.e. ADX_{16}) allocates 2 bits of additional range and 4 bits of additional precision as compared to the 10-bit Component Value Encoding Metric (i.e. ADX_{10}). The 2 bits of additional range are allocated in the most significant bits. The 4 bits of additional precision are allocated in the least significant bits. Figure 6 illustrates the allocation of the additional bits in the 16-bit Component Value Encoding Metric as compared to the 10-bit Component Value Encoding Metric.

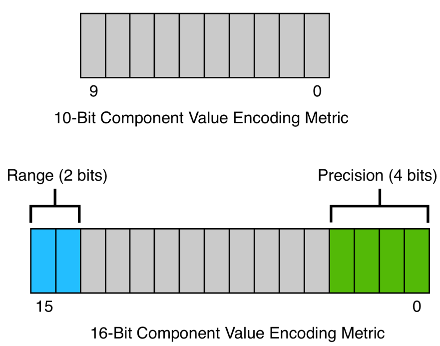


Figure 6 *- Bit Allocation of ADX_{16} and ADX_{10}*

The following formula is used to convert APD printing density values encoded using the 10-bit Component Value Encoding Metric to the APD printing density values encoded using the 16-bit Component Value Encoding Metric

$$ADX_{16} = ADX_{10} \times 16 \quad (5)$$

To convert APD printing density values encoded using the 16-bit Component Value Encoding Metric to APD printing density values encoded using the 10-bit Component Value Encoding Metric the following formula is used.

if FLOOR[ADX_{16} ÷16] is even

$$ADX_{10} = (ADX_{16} + 7) \div 16 \quad (6)$$

if FLOOR[ADX16 ÷16] is odd

$$ADX_{10} = (ADX_{16} + 8) \div 16$$

The FLOOR operator returns the value of 0 for fractional parts in the range of 0 to .9999…, i.e. it truncates fractions.

This method, known as "round to the nearest even" [6], is used in an attempt to minimize the rounding error that is introduced by the conversion and avoid accumulating additional rounding error if an image is repeatedly converted back and forth between ADX_{10} and ADX_{16}.

Conclusions

The Academy of Motion Picture Arts and Sciences' Image Interchange Framework project committee has proposed a new printing density metric and encoding for use with contemporary motion picture materials. The APD metric has been shown to be an excellent density metric for the measurement of negative and internegative films compatible with Eastman Kodak 2383 and Fujifilm 3510.

ADX has also been shown to be an appropriate encoding of APD values for use with the Image Interchange Framework. The 16-bit ADX component encoding metric is capable of encoding density ranges that exceed the capabilities of 10-bit encoding metrics currently in use. ADX also encodes APD values such that neutrals are represented by equal ADX code values.

For more information on the Image Interchange Framework contact the Academy of Motion Picture Arts and Sciences' Science and Technology Council at councilinfo@oscars.org.

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