A NOVEL CALIBRATION TARGET FOR FILM SCANNERS

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Abstract

This paper describes the use and theory of operation of a new kind of optical filter assembly for color calibrating desktop film scanners. The stability of such optical filters and their potential for miniturization provide some compleling advantages over the use of film calibration targets.

Introduction and Overview

This paper describes an new type of scanner calibration target that, in combination with color transform software, allows color-accurate images to be acquired from digital film scanners. The software combines the scanner characterization data obtained using the calibration target with the spectral transmission data of the film being used to fully calibrate the scanner without needing access to a physical film target.

The Calibration Target

The calibration target (Figure 1) has been designed with the form factor of a 35mm slide and consists of two optical elements: a linear, neutral density gray ramp, and a linear variable spectral filter. The precise calibration data that is supplied with each calibration target is referenced to the fiducial marks etched onto each of these optical filter elements.

1 LightSource, Inc.
2 Savitar, Inc.

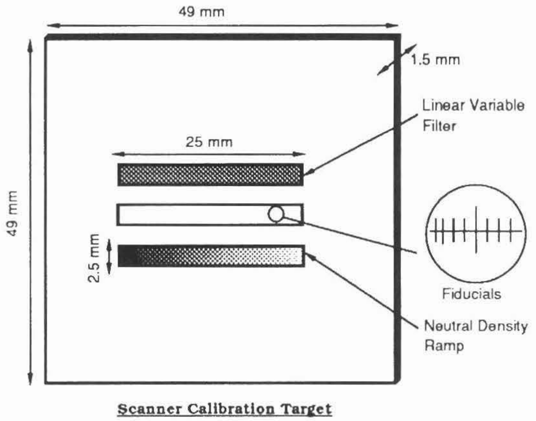
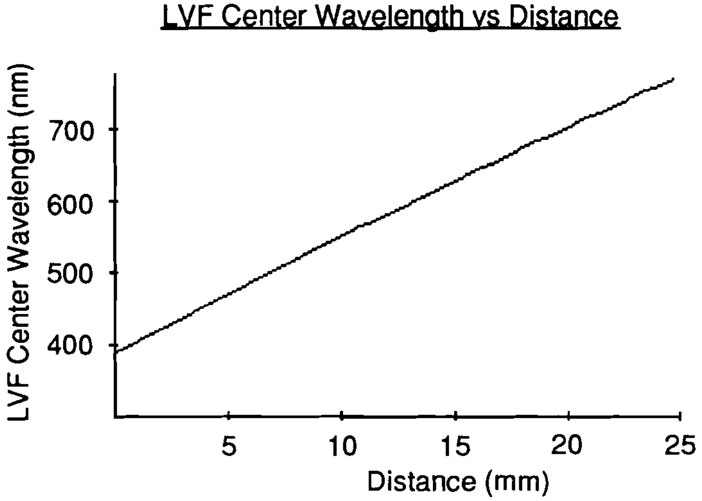


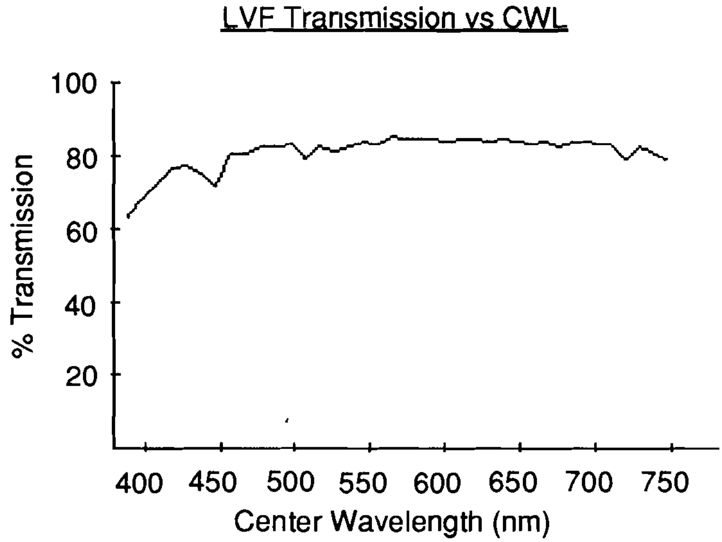
Figure 1

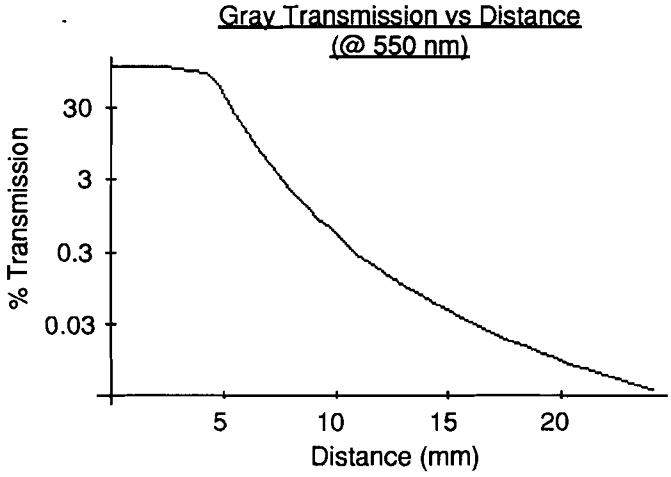
The neutral density ramp has constant transmission across the visible spectrum and varies linearly by two orders of magnitude in transmission across the filter element. The neutral density ramp is used for balancing the scanner red-green-blue channels to neutral gray and provides an absolute standard of gray for varying light intensity. The filter also enables the linearity of a scanner's detector to be established.

The linear variable (spectral) filter is an interference wedge with a blocking Hot Mirror laminated to the optical cavity filter. The filter blocking is optimized for CCD scanners. The linear variable filter covers the range of 390 nm to 770 nm with center wavelength transmission rates in excess of 50% and out of band transmission less than 0.1%. Half power bandwidths are 10-15 nm. The center wavelength of maximum transmission varies linearly (+/- 5%) across the element. These filter characteristics are specified with the criterion that the incident light be collimated within a half cone angle of 10 degrees.

Representative Data Cuves


LVF Center Wavelength vs Distance


LVF Transmission vs CWL



Theory of Operation

The signal obtained at the output of a color separation channel in a color electronic scanner is the combination of the light source, the film dye set, the color separation filter and the radiation detector. The system can be modeled by a linear combination of these components. Let us first describe the spectral contributions of each element of the system.

The light source's contribution to the final signal is determined by the spectral radiance of the source, Nl watts-cm2/steradian. The value Nl determines the maximum number of photons available in the scanner system. The amounts of signal power arriving at the detector is determined by the transmission of the elements between the source and the detector.

Most color separation systems use Red, Green and Blue filters. Desktop CCD scanners typically use fairly broadband filters to optimize the Signal-to-Noise Ratio (SNR), while high-end graphic arts drum scanners (using photomultiplier tubes) use narrower band filters for better color separation. The calibration target is particularly valuable calibrating scanners with broadband filters.

In the model presented in this paper, the filtering action of scanner's filters, including the transmission of the optical system, will be denoted $^{\bar{x}}$Cl. The pre-subscript, $\bar{x}$, is used to show that C has three vector component (R,G,B).

The post-subscript denotes the wavelength dependence of the three vectors.

The model will assume that a single radiation detector type is being used in all channels. The action of the detector will be assumed to have two separable components: the responsivity and the actinic response. The response of the detector to an arbitrary distribution of light, A, can be written:

$$S = R(\int_{\lambda_1}^{\lambda_2} A_\lambda D_\lambda d_\lambda) \qquad (1)$$

where S is the signal output in volts, R is the responsivity of the detector in volts/watt, Al is the incident power in watts and Dl is the actinic response of the detector. Note that the signal output is a monotonic function of the input power, Al, but is not necessarily linear. Therefore, to fully understand the system we need to be able to separate the responsivity from the spectral response of the detector.

The final element in the model is the color film. The transmission of an arbitrary patch on the film will be noted $^{\bar{y}}$Fl. The pre-subscript is used to represent that the transmission of the dye set is a three vector set, Cyan, Magenta and Yellow. The post-subscript is used to show the spectral dependence of the dyes. The function $^{\bar{y}}$Fl is given by:

$${}_{\bar{y}}F_\lambda = 10^{(\alpha \mathrm{Log}\, C + \beta \mathrm{Log}\, M + \gamma \mathrm{Log}\, Y)} \qquad (2)$$

where a, b and g represent the concentrations of the Cyan, Magenta and Yellow dyes respectively. C, M, Y are the spectral absorption coefficients of the respective dye sets.

The signal reported through each filter channel of the scanner is,

$$S = R(A_0\cdot\Omega\cdot\int_{\lambda_1}^{\lambda_2}({}_{\bar{y}}F_\lambda\cdot D_\lambda\cdot{}_{\bar{x}}C_\lambda N_\lambda)d\lambda)\ \text{volts} \tag{3}$$

Where Ao is the area of the detector and Ω is the solid angle of the optic illuminating the detector.

The equation above can be rewritten in a simple form:

$$S = R\ (\int_{\lambda_1}^{\lambda_2}({}_{\bar{y}}F_\lambda\cdot{}_{\bar{x}}P_\lambda)d\lambda)\ \text{volts} \tag{4}$$

where:

$${}_{\bar{x}}P_\lambda = A_0\cdot\Omega\cdot D_\lambda\cdot{}_{\bar{x}}C_\lambda\cdot N_\lambda \tag{5}$$

is the spectral power in (watts/micron) seen by a detector element in a given channel when no film is in the scanner gate.

Three functions control the signal output of the scanner: R, the responsivity of the detector; ${}^{\bar{x}}$Pl, the spectral power available in the channel; and, ${}^{\bar{y}}$Fl, the spectral transmission of a given patch of film.

The calibration target is used to supply the needed information on the responsivity, R and the spectral power, ${}^{\bar{x}}$Pl.

The spectral properties of film patches, $\bar{y}$Fl, are found by spectral photometric measurement and the spectral transmission data is then placed in a data table.

Let us now describe how the calibration target is used to determine the two factors that describe the scanner, R and $\bar{x}$Pl.

The responsivity of the detector can be mathematically broken into two parts, R and Dl.

R is the function that gives the signal volts per watt of input signal and Dl is the spectral sensitivity of the detector. The spectral sensitivity, Dl, is going to be assimilated into the function $\bar{x}$Pl. That being the case, the responsivity can be found for each channel by attenuating the illumination on the detector with a series of neutral densities. This calibrates each channel for an assumed uniform input across the color separation channel.

The assumption of the uniform input can be made since all the spectral variance is being assigned to $\bar{x}$Pl. It is, however, important to calibrate the channel responsivity before the determination of $\bar{x}$ Pl since the detector may not be linear in its response.

Once the responsivity of the detectors has been measured, the spectral filter portion of the calibration target can be used to determine the functions, $\bar{x}$Pl. As described above, the spectral filter has a known transmittance as a function of wavelength. This is then used to convert the measured signals to a uniform equivalent power.

The signals obtained from the scan of the spectral target are block averaged to obtain the proper sample bandwidth in the direction of the wavelength scan and to obtain a better signal to noise ratio by averaging detector elements perpendicular to the wavelength scan.

By using the responsivity, R, each detector signal is corrected to a unit of power.

After correction, the signals are block averaged to produce a more accurate single detector narrow band power estimate of $^{\bar{x}}Pl$.

The power scale factor is chosen such that:

$$ {}_{\bar{x}}S = R\left(\sum_{\lambda_1}^{\lambda_2} {}_{\bar{x}}P_{\lambda}\right) \tag{6} $$

where $^{\bar{x}}S$ is the signal observed in the channel when the gate is open. The sum of the individual scaled spectral power contributions put through the responsivity function should equal the observed open gate signal, $^{\bar{x}}S$, for each channel.

After calibration, the $^{\bar{x}}Pl$ and R functions have been determined and stored in a data file. The signal for any color patch in a standard film target are found by,

$$ S_C = R\left(\sum_{\lambda_1}^{\lambda_2} {}_{\bar{y}}F_{\lambda} \cdot {}_{\bar{x}}P_{\lambda}\right) \tag{7} $$

where R and $^{\bar{x}}Pl$ are found from the calibration step, and $^{\bar{y}}Fl$ are the stored values of the spectral transmittance for the various steps of the standard color chart on a given film product.

Conclusion

Equation (7) above allows the scanner RGB signal response to each color patch on a given film product to be calculated. The CIE values for each of the same color patches has been calculated and stored in a software data table. By correlating the calculated RGB scanner response with the stored CIE values for each of the target's color patches, a scanner RGB to CIE transform can be derived. Subsequent scans can then be passed through this transform to translate them into CIE color coordinates.

If the system's output device (monitor or printer) has been similarly referfenced to a CIE color space, it is now possible to translate between the scanner RGB space and the RGB or CMYK color space of the output device.

In addition, by using calibration target to periodically re-evaluate Dl to compensate for scanner drift, a correction to ${}^{\bar{x}}$Pl may be generated without disturbing the previously computed scanner RGB to CIE color transforms.

The equations above show that the calibration target can be used to predict the signals that would have been produced if the original standard color film target had been scanned. The advantage of the procedure is simply that it does not actually require the use of a physical film target by the scanner operator.

The calibration target's stability makes it a less expensive alternative to film calibration targets and will enable future scanners to be self-calibrating by supporting embedded color calibration technology.

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