Colour Characterisation of a Digital Cine Film Scanner

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Abstract

This study presents a solution to the problem of characterising a cinema film scanner, used in the field of digital film postproduction. The scanner digitises negative films, and produces a digital positive version of each frame so that special effects can be added by computer. Negatives are scanned because they provide the most appropriate medium from the point of view of preserving the integrity of the artistic intent, they are however meaningless in colorimetric terms and this complicates the characterisation issue. Since Analytical models of the film printing process are impractical because of the commercially sensitive nature of some of the data required, the solution presented uses a multi-stage interpolation that characterises the different stages of the film printing process. The first consists of identifying the relationship between negative and positive densities. The second consists of identifying the relationship between positive (or print) density and colorimetry. The results show that the distance weighted interpolation technique yields the most satisfactory results.

1. Introduction

Digital technology is slowly achieving ubiquity in the entertainment industry. Already digital technology in the form of compact discs has come to dominate the recording industry, DVDs are expected to achieve similar success in the home entertainment market. The cinema production industry seems likely to fall in with this trend in the near future, with the existence of high quality digital cameras and projection equipment, based on digital micromirror device technology for example. There is a requirement colour management in the broader field of digital cinema, the foundations for which are being laid in a project, of which the work reported here forms a part.

At present cinema is still dependent on robust and well-understood analog technology, although films are coming to rely increasingly on digital special effects. While the film industry still depends almost entirely on the celluloid medium, effects are added to scenes by manipulating digital representations of individual film frames. This requires that sections of film are digitised. The digitisation process involves the use of a scanner, which usually performs a form of densitometry; the RGB values of the scanner being dependent on the light transmitted through the film.

This study discusses a technique for the colorimetric characterisation of a scanner, purpose built for the scanning of digital film. In order to identify a suitable characterisation procedure, the scanning process is examined, and several characterisation techniques are compared as potential solutions to the problem.

2. The Scanning Process

Generally negative film is used in the scanning process for a number of reasons; the negative is the basic raw material out of which, ultimately, the art is extracted; functionally the low gamma of negative film makes it particularly amenable for scanners using CCD technology with limited dynamic ranges.

Negatives present a significant challenge to colour management since their colorimetry is meaningless. Coloured couplers are used in order to prevent unwanted absorptions, which give negatives an overall orange tinge, and the colours are reversed in a way that often eludes straightforward mathematical modeling (see the discussion on analytical models below). The only way of assessing the colorimetry of a negative is to produce a positive for measurement. This requires a printing process that can have variable effects on the colour.

The latitude of negative film is greater than that of print film, since it contains a considerable amount of scene information, only a subset of which is required to express the artistic intent of the Director of Photography. Even if the image was over or underexposed when captured, much of the required information is retained, and can be extracted to form the positive. By adjusting printing light settings in the laboratory, the ”look” of a film (in photographic terms) is determined by how an image is extracted from a negative. Thus the printing process adds further modelling problems.

The digital representations that result from the scanning process are invariably based on a densitometric assessment of the negative, which fact will require some explanation.

Film negative is a transmissive medium, and the scanning process involves assessing the amount of light mediated by the negative from the scanner's light source[1]. The transmittance factor T is the ratio of light transmitted by a medium, I_t, to the amount of light incident on the sample I_t, thus.

$$T = \frac{I_t}{I_i} \tag{1}$$

Density is related to transmission by an inverse logarithmic relationship[1], as follows.

$$D_t = log_{10}\left(\frac{1}{T}\right) = -log_{10}(T) \tag{2}$$

A perfect transmitter would have a transmittance factor of unity, and the resulting transmission density would be $log_{10}(1) = 0$. Conversely a perfectly opaque sample would have zero transmittance, and infinite density. The scanner in question is thus a form of densitometer.

Coincidentally density is used extensively in the film industry for colour control, for the reason that it is more closely related to colorant concentrations, and it is easy to measure. A number of standard techniques have been defined for densitometric measurements, that are used in the cinema industry, in particular Status A and Status M. Both of these standards specify a light source, and three coloured filters, so as to measure the transmission density in three (RGB) channels.

The red transmittance factor, for example is determined by the amount of red light mediated by the sample being measured, and would be determined as follows.

$$T_R = k_R \sum_{\lambda} T(\lambda) F_R(\lambda) \tag{3}$$

Where the subscript R denotes the values for red (the densities for green and blue can be similarly determined), F_R refers to the red filter, T refers to the transmittance, and k_R is a constant ensuring $T_R = 1.0$ for perfect transmission. The red density measure, D_R is calculated from equation 2.

Although cyan, magenta, and yellow dyes are used in film, the spectral peaks in the filters defined in the Status A, and M standards are designed to coincide with the absorption troughs, in the dyes used in negative and positive film (where the metric varies most with dye concentration), and so the terminology is strictly correct[2].

Having examined the scanning issue, the process of extracting colour information from negatives is discussed in the folowing section.

3. Towards a Solution

The colour characterisation of a film scanner requires that colour information is extracted from negatives notwithstanding the inherent difficulties of the problem. Perhaps the most obvious solution would be to consider an analytical model of the film printing process.

Such models exist for the characterisation of monitors and cameras, where certain assumptions can be made that facilitate the process. In the case of monitors the assumption of constant chromaticity often enables CRT monitors to be characterised using a set of one dimensional look-up tables, and a suitable 3 × 3 matrix.

In order to construct an analytical model, the transmitted light intensity at a number different wavelengths throughout the visible spectrum is required[3], usually sampled at five or ten nanometre intervals. A possible technique is outlined in the following stages.

1. Compute the optical density of each dye layer at each wavelength by multiplying the absorption spectrum of the assumed dye by its concentration (i.e. apply Beer's Law - the absorbed radiation of a medium is proportional to the concentration[4]).

2. compute the total density at each wavelength by adding the three dye densities, and the density of the stain of the substrate;

3. convert density values to transmission values (using an anitlog operation);

4. compute the transmitted light intensity spectrum by multiplying the intensity of the light source at each wavelength by the transmission value of the film.

5. Convert the intensity spectrum to XYZ tristimulus values using the standard observer colour matching functions.

In order for this model to work the dye absorption spectra for each film stock are reqruired, as are the dye concentrations. In many cases this information is not readily available from film manufacturers, and is often considered to be commercially sensitive. In the absence of information about the dye absorption, the approach pursued in the study is that of "maximum ignorance", and to obtain measurements for the density and colorimetry of an image and use curve fitting techniques to identify a relationship.

The solution offered consists of a multistage approach problem, based on the diagram in Figure 1.

The scanner characterisation process consists of three transforms, indicated by the arrows in Figure 1. The relationship between Cineon values and Status M is defined in the Cineon standard[5]. The relationship between negative

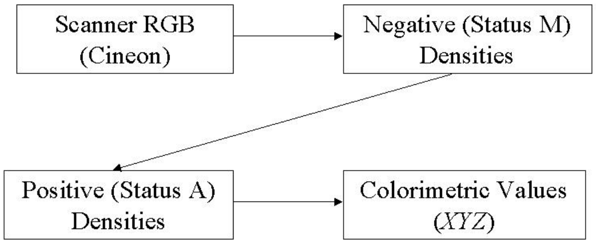

Figure 1: *Transforms required for Digital Scanner Characterisation*

and positive density, and the relationship between positive density and colorimetry, are altogether more complex, and require more careful consideration.

The justification for this modular approach lies in the fact that the relationship between positive density and colorimetry is stable for most most film stocks, however the relationship between negative and print density can vary due to exposure corrections. These corrections are usually performed by the adjusting printer light settings in the laboratory, which has the effect of adding a constant to the print density in the final result. The constant is determined by the Laboratory Aim Density or LAD technique[6]. Each film, whether positive or negative, has density data specified by the manufacturer for a single mid-grey patch (the LAD patch). The LAD patch is usually included in every reel of film to be developed, and the data includes the Status M value that should obtain for the patch when the negative is produced, or the Status A value for the print version. The discrepancy between the specified LAD values, and those obtained during the printing process, is used to determine the exposure correction factor. This requirement for exposure correction explanins the need for a multistage process, which affords the flexibility required to accommodate printing adjustments.

Three techniques were tried for both of the transforms described here, including least squares (LS) fitting[7], look-up tables[8,9](LUTs), and distance weighted interpolation[10] (DW). These were tried on modelling the density relationship (from negative to print density), and the density to colorimetry relationship. One innovation presented in this paper was to use the Mahalanobis distance with the distance weighted interpolation technique.

The Mahalanobis Distance[11] between two vectors in the set $\{x_1, x_2, ..., x_i\}$ is defined as follows

$$d^2(x_i, x_j) = (x_i - x_j)\Sigma^{-1}(x_i - x_j) \qquad (4)$$

In this case Σ refers to the variance-covariance matrix for the set of vectors $\{x_i\}$, and is defined as follows for a set of three-dimensional vectors.

$$\Sigma(x) = \begin{bmatrix} \sigma_1^2 & \sigma_1\sigma_2 & \sigma_1\sigma_3 \\ \sigma_2\sigma_1 & \sigma_2^2 & \sigma_2\sigma_3 \\ \sigma_3\sigma_1 & \sigma_3\sigma_2 & \sigma_3^2 \end{bmatrix} \qquad (5)$$

Effectively this scales the axes of the vector space so that distances are less dependent on the variance within the data. Generally the Euclidean distance is used in distance weighted interpolation, and it is expected that the Mahalanobis distance will represent a more useful measure for those colour characterisation problems where performance can vary depending on the interpolation data.

The results obtained for all of the techniques discussed above, are presented in the following section.

4. Experimental Method

The data upon which the following work is based consists of a thousand film samples, each frame depicting a single colour (both positive and print film were used). The samples were chosen to form a regular array of points in Cineon space. The sample set was partitioned in order to obtain a training set with which to develop the model, and a test set of unseen data to verify its performance. A large training set (800 samples) was therefore extracted, the remainder formed a test set. The test samples were chosen so as to represent as even a sampling of Cineon space as possible.

The densities of these frames were measured using an X-Rite 310 densitometer. The colorimetry of the positive frames was measured using a Colortron device whose accuracy was tested using an ISO IT8.7/1 image. The median of the error of the Colortron measurements was within $2\Delta E_{ab}$ of the measurements given with the image.

4.1. Density Transform

In this transform, as in the other, LS fitting performed least well out of the three techniques. The LS Modelling technique in this case, sought to fit a second order polynomial to the data. While it may be argued that a quadratic equation is insufficient of itself to deal with the many nonlinear processes involved in film printing, the approach taken was to consider a number of preprocessing techniques, and applying them to the training set, in order to improve the overall performance. These included, taking antilogs of the logarithmic density measures, both separately and in combination. In the event the best results were obtained with the unadjusted data, and was still unsatisfactory, with mean errors for predicted print density of 1 (± 0.1).

The results for distance weighted, and tetrahedral interpolation were considerably better, and the mean absolute difference between measured and predicted print density are shown in the following table (Table 1).

Status M → Status A				
Interpolation	Mean R error	Mean G error	Mean B error	Mean RGB error
LUT	0.35	0.27	0.25	0.64
DWI (Euc)	0.06	0.06	0.08	0.14

Table 1: *Density Transform Results (Mean RGB error refers to the mean Euclidean distance between predicted and measured results)*

Status M → Status A			
Comparison	Red	Green	Blue
SD (Density)	0.18	0.27	0.19
Percentage	100%	100%	85%

Table 2: *Density Transform: Percentage of Samples Within Density SD*

This suggests that the distance weighted interpolation technique is considerably better. In order to address the issue of whether the interpolated results are good enough, the inherent variability of printing density measurements was assessed.

Part of this is accounted for by the innate variability of the chemical processes involved in the development of film, which makes it extremely unlikely that there will be exact repeatability of density measurements for any two frames, even if they are exactly the same colour. Furthermore the samples are printed onto film using a film recorder, which converts the digitally generated colours into their celluloid representations. This machinery also contributes further uncertainty into the system.

The samples used in the experiment were determined in Cineon space, which is supposedly determined by the density of the negative. In which case two different samples with the same red cineon value for example, should have the same (or similar) red density values. Thus the Status A densities of samples with the same cineon values for a particular channel were collected, and their standard deviation calculated. Thus a measure of the whole system variability is obtained. If the predictions fall within the limits of the system variability, then this is an indication of the acceptibility of the errors.

The percentage of predicted Status A RGB values, where the error between measured and predicted was less than the calculated standard deviation is listed in Table 2, and graphically in Figure 2. This gives a measure of the extent to which the predictions fall within the inherent variability of the measurement system, and thereby a means of assessing the success of the transforms.

Attempts to improve the distance weighted interpolation algorithm using the Mahalanobis distance failed to re-

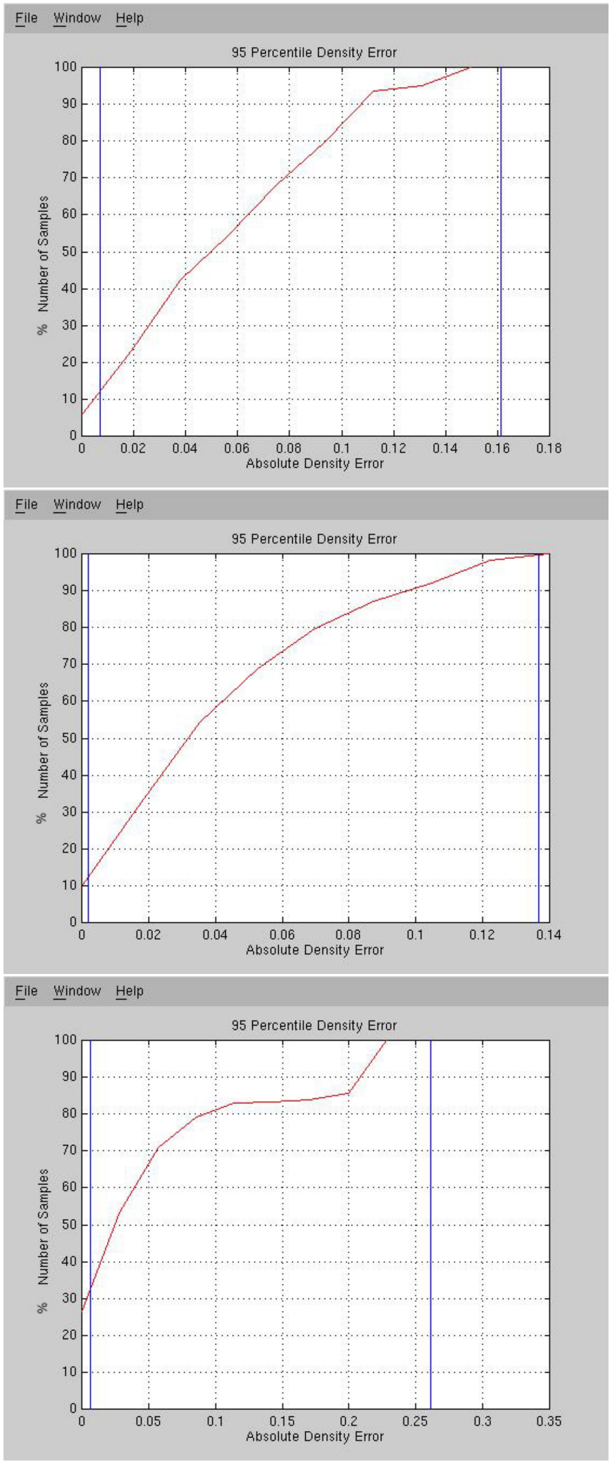

Figure 2: *Cumulative density errors (the vertical lines indicate the 95% confidence limits).*

Status A $\rightarrow XYZ$		
Technique	Median ΔE^*_{ab}	Maximum ΔE^*_{ab}
LUT	6.50	25.39
DW (Euc)	2.99	15.73
DW (Mah)	2.23	9.67

Table 3: *Density Colorimetry Transform results (Euc refers to Euclidean Distance, and Mah to Mahalanobis distance)*

duce the error in this case, giving results that were comparable to the Euclidean Distance measure.

4.2. Density-Colorimetry Transform

In this case the attempt is made to predict colorimetry of an image from film print density. As before, a quadratic LS approach again proved unsuccessful, despite further attempts to preprocess the data to make it fit the model. In this case antilogs of the input density were used. Also the output (XYZ) data had logs taken (so as to relate it to colorimetric data), and cube roots were calculated (to obtain a more physiologically plausible colorimetric measure). The preprocessing was undone, in order to obtain the $\Delta E_{ab}s$ between measured and predicted results. The results were still unsatisfactory, with median errors of 62 ΔE_{ab}.

The results for the other techniques are displayed in Table 3, in all cases data preprocessing failed to yield any improvement. As can be seen from the table, the colour errors for distance weighted interpolation using Mahalanobis distance were roughly comparable with the error of the measurement device. Median ΔE_{ab} between measured and predicted colorimetric values was slightly greater than two, which compares with that of the Colortron.

This table illustrates that the Mahalanobis distance provides substantial improvement. Further evidence of the success of the distance weighted technique can be attested by consideration of the percentage of errors below particular ΔE_{ab} values.Figure 3 illustrates this particular point.

The outcome of this transform has therefore proved successful. This in essence forms the entire scanner characterisation process.

5. Conclusions and Further Work

All of this work would suggest that a successful solution to the problem of scanner characterisation has been found, and that the Mahalanobis distance represents a significant improvement for colorimetric data. This is no doubt due to the metric peculiarities of CIELAB space, while the Mahalanobis distance resembles the CMC colour difference equation.

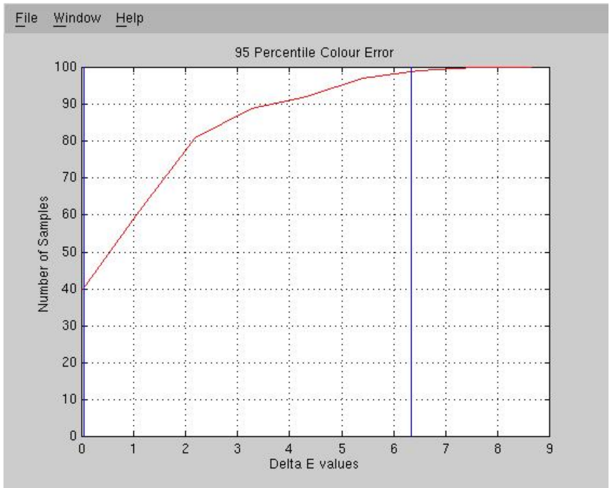

Figure 3: *Density-colorimetry relationship results*

The models of the printing process generated here will allow for the characterisation of the scanner. The nature of the scanner's principal input medium (film negative) has made this task much more complex than would normally be the case. Simply using a suitably colorimetrically-defined target image, for which more straightforward single stage techniques would normally suffice proved entirely inappropriate due to the nature of the problem. One of the significant contributions of this work therefore is a method for characterising film negatives.

Work is ongoing using other techniques to interpolate accurate colorimetric values from scanner data. Work on these techniques will be reported in due course.In the mean time the scanner characterisation is being incorporated into a larger colour management problem, involving the accurate preview of film on screen.

6. Acknowledgement

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Biography

Leonardo Noriega received his BA degree in Medieval and Modern History from University College London in 1989, his MSc in Computer Science at the Unversity of Kent at Canterbury in 1991, his MSc in Machine Perception and Neurocomputing from Keele Unviersity in 1993, and his PhD from the Nottingham Trent University in 1998.

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