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COLORIMETRY IN TELECINE

INTRODUCTION

Historically, the role of telecine has been to reproduce as accurately as possible the picture on the film, notwithstanding that this did not necessarily represent the best reproduction of the original scene.

In the film process as a whole distortions occur, some of a random nature and some of a predictable nature. The random errors can be due to variations in film manufacture, exposure, processing, grading etc, and if such errors are to be corrected it must be on a scene by scene or reel by reel basis, as appropriate. The predictable errors, however, are largely capable of correction within the telecine equipment, and are mainly due to the increased contrast ratio, the associated increased gamma, and crosstalk between dye layers. The crosstalk errors are in-built in the film and are due to limitations imposed on the manufacturer by the materials at his disposal.

The increased contrast ratio and gamma of the normal film print are deliberately introduced so that, with direct projection in the dark surroundings of a cinema, the effects of the dye crosstalk are largely offset.

The television system is not able to handle the very high contrast ratios of up to 300 or so which are commonly to be found in film prints and, unless the gamma is corrected and this ratio reduced, much of the information contained on the film is lost.

It is paradoxical that the comparatively low contrast handling ability of the television system removes the need for the extra contrast and gamma, in fact they become an embarrassment. At the same time, the electronics involved in television allow correction of the very condition which they were intended to allay in the first place.

The need to correct the crosstalk as well as the gamma comes about for other reasons. Live television cameras perform what might be termed a broadlobed analysis of the original scene.[1] In the case of film this analysis is performed in largely the same way by the original film with its broad overlapping taking responses and, once this process is complete, no further information relating to the original scene can be obtained from the film beyond that contained in the three dyes in the final print. For this reason it is logical to consider a telecine as a decoder of the film information, both on the grounds of the best absolute fidelity and possibly even more important, the need to match film with live or taped programme material where the reproduction has not been subjected to the distortions associated with film.

There is a limit to the range of colours that can be reproduced by colour film when projected, as there is also a limit to the accuracy with which any particular colour within that range can be reproduced. These differences will be determined to some extent by the spectral sensitivity of the emulsion layers in the original film, but mostly by the nature of the dyes in the final print.

THE FILM IMAGE

The range of colours that may be reproduced by a typical reversal colour film are shown in figure 1. The area shown is for dye concentrations giving densities of 2·0 in the main absorption bands. It is a significant attribute of a subtractive system that if the dye concentration is increased the colour saturation is increased but the maximum luminance is decreased, a limitation which does not necessarily apply to additive systems. For comparison, the gamut covered by a typical set of display tube phosphors is also shown in figure 1. Practically it has been assumed that the dye concentrations on the film are related to the individual layer exposures by a simple power law:

$$\text{Density} = -k\cdot\log\,(\text{Exposure}) \quad \ldots\ldots\ 1$$

In practice this is only true for a limited range of densities. A further effect, known as 'Interimage

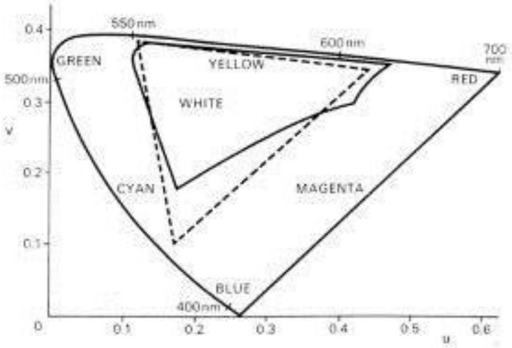

Fig.1 Gamut of colours reproduced by subtractive colour process (inner solid line), BREMA phosphor set (dotted line) and spectral locus (outer solid lines).

Effect', modifies this simple relationship. This term describes the interaction of the individual dye layers; that is, the effect whereby the development of one dye layer will affect the other dye layers. For example, after selective exposure of the cyan forming (red sensitive) layer to a flat field of light, the yellow forming (blue sensitive) layer is selectively exposed to a grey scale. The result is that the concentration of the cyan dye is reduced by production of yellow dye (Fig.2). The results of the Interimage Effect changes the value of k according to the colour of the exposing light. The effect may or may not be desirable depending upon the amount by which the dye layers interact.

A typical set of film emulsion sensitivity characteristics compared with the ideal analysis curves for the BREMA phosphor set is shown in figure 3. It will be noted that the blue, and to an even greater extent, the red, taking lobes of the film are set well to the extremes of the visible spectrum to improve the performance of the film.

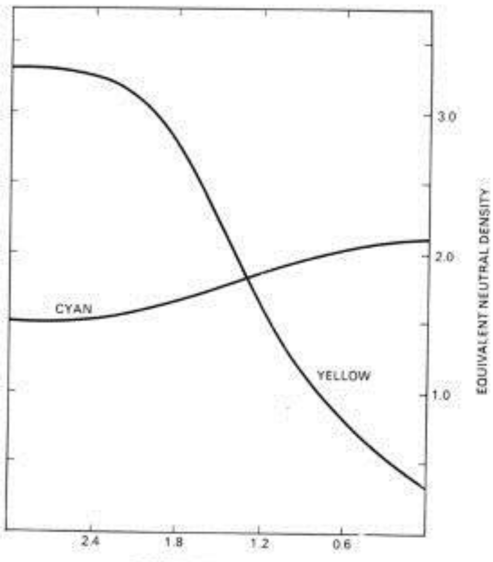

Fig.2 Interimage effects.

GETTING THE BEST FROM THE FILM IMAGE

The spectral sensitivity characteristics of the film are not precisely those that would be chosen for a live television camera. However, if the telecine equipment is able to remove the major errors due to the film dyes, a fair reproduction may be still obtained. The objective is to read the original red, green and blue exposures as measured by the film. To improve the overall performance of the system it is necessary to modify electrically the effective spectral sensitivity characteristics of the film to correspond to the ideal taking characteristics shown in figure 3.

Theoretically, the correct way of achieving this is to matrix the colour signals when they are in a linear form, having previously performed a logarithmic masking function to remove the dye crosstalk errors. Figure 4 shows the block diagram of a processing system to perform such functions. Clearly this system would be complex and somewhat unwieldy in operation.

A satisfactory compromise is to optimize the logarithmic matrix to include as far as is possible the required linear matrixing. To obtain the best results the telecine spectral response should clearly be made as narrow as possible and positioned to include a minimum of dye errors in the signal. The optical response lobes should thus be made as narrow as possible consistent with the sensitivity of the equipment. As the width of the taking lobes is increased the electronic correction becomes less accurate due to the fact that the dyes are read at a multiplicity of different gammas.[2] If the telecine has sufficient sensitivity to allow very narrow lobes it is possible to consider the dye reading to have a single gamma value. With narrow lobes the matrix coefficients required are reduced and hence the overall signal-to-noise ratio improved, while calculation of the matrix equations become less involved.

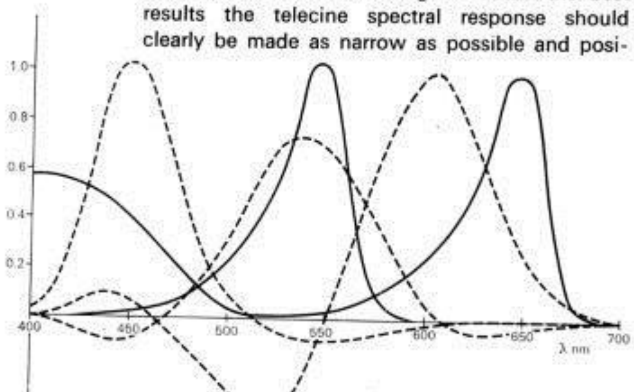

Fig.3 Film spectral sensitivity characteristics and ideal characteristics dotted.

MATRIX CALCULATION

If it is only required to correct for the dye errors, calculation of the necessary logarithmic masking factors is a simple matter. The first step is to draw spectral lines which correspond to the narrow lobes of the camera on the dye characteristics. The dye densities at the points of intersection are read off and written in the form of a matrix; thus

$$\begin{bmatrix} Dr \\ Dg \\ Db \end{bmatrix} = \begin{bmatrix} dcr & dmr & dyr \\ dcg & dmg & dyg \\ dcb & dmb & dyb \end{bmatrix} \begin{bmatrix} C \\ M \\ Y \end{bmatrix} \qquad \ldots\ldots 2$$

where Dr, Dg etc, are the total densities read by the camera, dcr, dmr, etc, the individual dye readings and C, M etc, the peak dye densities which are related to the exposure of the film by equation (1),

$$\text{or} \quad \begin{bmatrix} Dr \\ Dg \\ Db \end{bmatrix} = \begin{bmatrix} A \end{bmatrix} \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

$$\text{when} \quad \begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} A \end{bmatrix}^{-1} \begin{bmatrix} Dr \\ Dg \\ Db \end{bmatrix}$$

The factors Dr, Dg and Db are obtained by taking the logarithm of the red, green and blue camera signals, the resultant signals being fed to a matrix having the factors of the inversion matrix $[A]^{-1}$. After matrixing a gain adjustment may be made to obtain the required gamma before the signal is fed to the exponential (antilogarithmic) amplifier. The resultant output is then the effective red, green and blue exposures as seen by the film. If it is desired to correct for the film spectral sensitivity characteristics and to take into account the display tube phosphors, the task becomes more complex. To calculate the matrix in this case it is necessary to make a mathematical model of the system. Figure 5 shows the model in block diagram form; (the test colours are the same as are used in the model referred to in the previous article).[1] The matrix calculation is by a method of 'least squares', a process which minimizes the differences between the ideal and real responses. The 'Dye Process' may include multiple processes, such as negative-positive printing, positive-internegative-positive, and so on. Only a simple reversal process has been considered here. However, it is sufficient to consider a simple reversal process as the resultant dyes are similar in nature in each case.

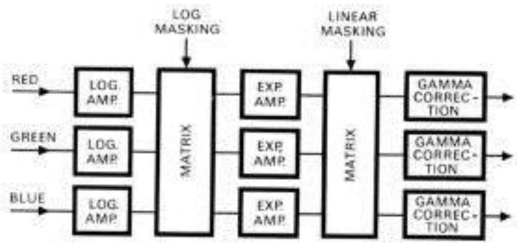

Fig.4 Theoretical block diagram of processing system.

CALCULATION AND ASSESSMENT OF ERRORS

The mathematical model just mentioned can be extended (as shown in figure 5) to calculate the resultant error in the reproduction under various conditions. The results that follow are for a typical reversal film process. The telecine spectral characteristics are those of the Marconi Telecine, type B3402.

Figure 6 shows the computer output when the program is correcting for the film spectral characteristics and the dye characteristics. The matrix is arranged so that

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 11 & 12 & 13 \\ 21 & 22 & 23 \\ 31 & 32 & 33 \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

Comparing the results of figure 6(a) with those of figure 6(b) where the correction was for the film dyes only, it can be seen that the red output signal (R) has a very high negative 'g' component (element 12) in the first case. This is due to an attempt to provide a negative lobe on the red response to correspond to the ideal taking characteristic (see figure 3). For the same reason there is a positive 'b' signal in the R output (element 13). Similar comparisons may be drawn for other components in the matrix. Figure 7 gives the results of a particular computer run, showing part of the test colour set only. The first data set, 7(a), shows the result with no correction. The chrominance and luminance errors can be seen to vary considerably over the range of colours shown. The second data set, 7(b), shows a reduction of the major chrominance errors but a corresponding increase in errors in other colours, cyan in particular, when the correction matrix of Figure 6(a) is used. Another notable effect is the large increase in the luminance error of the red and magenta, an increase of some nine per cent in the worst case. This is because the masking correction for the film spectral sensitivity errors can only be approximate. Because the major failing of the film is in the red sensitive layer characteristic the first row of the camera matrix was modified to give sixty per cent correction and the result is shown in figure 7(c).

Although some of the errors have increased the large errors have been reduced. By similar manipulation it is possible to shift the emphasis to areas where minimum errors are desired. Alternatively, more of the particular colours may be included in the set of test colours. An overall comparison of the two corrected and non-corrected results shows that the general effect of the correction is to remove major errors and, in some cases, to increase the lesser errors in a levelling process. This effect is inevitable as the correction for the film spectral sensitivities can only give an approximation to the required result, even if a linear matrix is used.

CONCLUSION

While it has only been possible to print a small selection of the data which has been produced, sufficient has been included to show the general

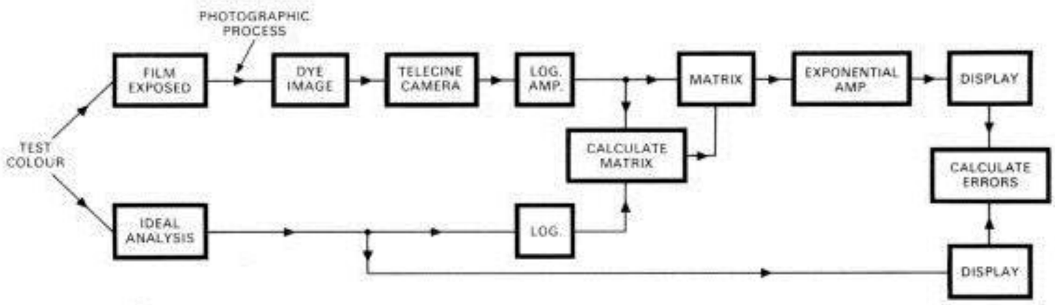

Fig.5 Mathematical model, block diagram.

effects of electronic correction as a means of improving colorimetric performance. As has been indicated, the spectral sensitivities of the film are not ideal, for practical reasons and because they are optimized to get the best from the subtractive reproduction system.

The errors due to the dye system can be exactly compensated by the logarithmic masking. The main source of colorimetric error remaining in the telecine system is due to the film spectral response.

REFERENCES

1 V. D. Crowley: Colorimetry in Television, Sound and Vision broadcasting, Vol. 13, No.2, Summer 1972.

2 D. A. Pay and A. Fremont: Gamma in Telecine, Sound and Vision broadcasting, Vol.13, No.1, Spring 1972.

CAMERA MATRIX			GAMMA
1.4924	-0.7539	0.2615	0.3764
-0.1392	1.3710	-0.2318	0.2893
-0.1795	-0.4051	1.5846	0.2824

6a

CAMERA MATRIX			GAMMA
1.2086	-0.1878	-0.0208	0.3785
-0.1993	1.2572	-0.0579	0.2810
-0.0278	-0.2774	1.3052	0.2906

6b

Fig.6 Computer output with matrix correcting for dye and film spectral response (a) and with matrix correcting for dye only (b).

TEST	CAMERA ANALYSIS			IDEAL ANALYSIS			CHROM	LUM
COLOUR	U	V	L	U	V	L	ERROR	ERROR
BLUE	0.1763	0.2796	0.2905	0.1923	0.2646	0.2999	5.7012	1.6087
CYAN	0.1719	0.3055	0.5181	0.1757	0.3049	0.5676	0.9808	4.6057
GREEN	0.1713	0.3316	0.3752	0.1772	0.3445	0.4493	3.6883	9.0982
YELLOW	0.1998	0.3428	0.5265	0.2052	0.3572	0.5980	3.9852	6.4362
ORANGE	0.2308	0.3391	0.3892	0.2541	0.3437	0.4585	6.2029	8.2806
RED	0.2704	0.3248	0.1698	0.3212	0.3309	0.1711	13.3348	0.3835
MAGENTA	0.2588	0.3035	0.1899	0.3067	0.2960	0.1767	12.6052	3.6162
MAGENTA	0.2210	0.2896	0.3803	0.2426	0.2709	0.3475	7.4279	4.5550
FLESH	0.2100	0.3240	0.4196	0.2221	0.3257	0.4403	3.1839	2.4375

7a

BLUE	0.1847	0.2561	0.2858	0.1923	0.2646	0.2999	2.9623	2.4304
CYAN	0.1640	0.3015	0.5230	0.1757	0.3049	0.5676	3.1482	4.1353
GREEN	0.1517	0.3453	0.4079	0.1772	0.3445	0.4493	6.6328	4.8823
YELLOW	0.1784	0.3582	0.5745	0.2052	0.3572	0.5980	6.9753	2.0294
ORANGE	0.2389	0.3529	0.4222	0.2541	0.3437	0.4585	4.6404	4.1659
RED	0.3421	0.3380	0.2265	0.3212	0.3309	0.1711	5.7281	14.1691
MAGENTA	0.3368	0.3130	0.2616	0.3067	0.2960	0.1767	9.0181	19.8138
MAGENTA	0.2651	0.2823	0.4289	0.2426	0.2709	0.3475	6.5600	10.6249
FLESH	0.2178	0.3330	0.4340	0.2221	0.3257	0.4403	2.1974	0.7360

7b

BLUE	0.1825	0.2554	0.2826	0.1923	0.2646	0.2999	3.5060	2.9969
CYAN	0.1666	0.3020	0.5284	0.1757	0.3049	0.5676	2.4748	3.6091
GREEN	0.1567	0.3454	0.4148	0.1772	0.3445	0.4493	5.3564	4.0387
YELLOW	0.1831	0.3581	0.5842	0.2052	0.3572	0.5980	5.7659	1.1843
ORANGE	0.2345	0.3529	0.4138	0.2541	0.3437	0.4585	5.6527	5.1820
RED	0.3222	0.3360	0.1905	0.3212	0.3309	0.1711	1.3573	5.4290
MAGENTA	0.3140	0.3058	0.2130	0.3067	0.2960	0.1767	3.1944	9.4362
MAGENTA	0.2496	0.2767	0.3880	0.2426	0.2709	0.3475	2.3554	5.5683
FLESH	0.2146	0.3328	0.4278	0.2221	0.3257	0.4403	2.6724	1.4573

7c

Fig.7 Colorimetric results without correction (a), using the figure 6(a) correction matrix (b) and with modified matrix (c).