RADIOMETRIC CORRECTION OF INFRA-RED AERIAL COLOR FILM

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Abstract

A method of correcting radiometric distortions for an infra-red color film is presented.

This method involves deriving matehmatical formulas, which explain various radiometric distortions, such as COS^4 law failure, overlaps of spectral sensitivities of multilayer film and unwanted absorptions of photographic dyes.

For some quantitative applications of IR color films, the correction scheme presented will give more useful result for an digital analysis of aerial IR-color photography.

1. INTRODUCTION

The visual interpretation techniques using color film and/or infra-red color film has widely been used as a standard qualitative analysis in the fields of Remote Sensing and photogrametry. These films have excellent resolution and have those sensitive layer in visible and near infra-red spectral region.

This multilayer film is coated onto a single base and the images of each layer of this multilayer film are automatically registered. So, there is no color fringing around the edges of objects. The color film is consider to be good multispectral sensor.

Recently, the importance of digital analysis techniques of these films has also been increased. However, the image on the film has a lot of radiometric distortions. So, it is necessary to correct these distortions before automatic quantitative analysis are performed.

In this paper, the basic concept on radiometric distortions involved in the aero color film and the correction techniques by a computer are reviewed and the useful of this correction process are discussed from automatic classification results of this film.

2. RADIOMETRIC DISTORTIONS CARRIED INTO COLOR FILMS

The radiometric distortions of an aero color film image are divided into two ways, first is caused by imaging camera system and the other is caused by the film characteristics itself.

Firstly, the irradiance at the focal plane of an aero camera is varied by COS^4 law in accordance with incident angle. Furthermore, path radiance occured by scattering of atmosphere and flares due to internal multiple reflection in the optical system are added. Therefore, the objects of same radiance which exist in different portions of the view field will give different irradiance of the focal plane.

Secondly, the input radiance energy through the camera lens is recorded on infra-red, red and green sensitive layer as dye densities of cyan, magenta and yellow respectively. In Fig. 1 shows block diagram of color film model. As the spectral sensitivity distributions of each layer overlapes one another, the required exposures to yield unit dye densities are different. Moreover, the amount of the produce dye which should be proportional to the input exposure will be affected by the dye yielding in another layer which is called as the inter-image effects occured during the developing process.

In addition, the spectral transmittance of three dyes have the spectral overlappings, known as unwanted dye absorptions. So, densities of the color film image measured through red, green, and blue filters are integral densities which contains the effects of the unwanted dye absorptions.

After the correcting these distortions, exact spectral radiance distribution of ground object can be obtained.

3. CORRECTION OF OVERLAPPING OF SPECTRAL DENSITIES OF DYES

The spectral density curves of cyan, magenta and yellow dyes after developing process have spectral overlaps each another known as unwanted dye absorptions, as shown in Fig. 2. So, when the dye densities of cyan, magenta and yellow layers are measured with sharp cut Red, Green, and Blue filters respectively, the integral densities do not always show the dye densities correctly, because of the mixing of unwanted dye absorptions of other dyes.

The integral densities of sampling for each filters are expressed in the following equations :

$$\begin{aligned} Dr &= Dc\ 650 + Dm\ 650 + Dy\ 650 \\ Dg &= Dc\ 550 + Dm\ 550 + Dy\ 550 \\ Db &= Dc\ 450 + Dm\ 450 + Dy\ 450 \end{aligned} \qquad (1)$$

where Dc, Dm, and Dy are the analitycal density for cyan, magenta and yellow dye at each peak wave lengths λ and Dr, Dg, and Db are measured integral density with Red, Green, and Blue filters.

By normalizing Eg.(1) with each analytical densities Dc, Dm, and Dy, the following equations are obtained :

$$\begin{aligned} Dr &= \frac{Dc650}{Dc650} \times Dc + \frac{Dm650}{Dm550} \times Dm + \frac{Dy650}{Dy450} \times Dy \\ Dg &= \frac{Dc550}{Dc650} \times Dc + \frac{Dm550}{Dm550} \times Dm + \frac{Dy550}{Dy450} \times Dy \\ Dc & \quad \frac{Dc450}{Dc650} \times Dc + \frac{Dm550}{Dm550} \times Dm + \frac{Dy450}{Dy450} \times Dy \end{aligned} \qquad (2)$$

$$\begin{pmatrix} Dr \\ Dy \\ Db \end{pmatrix} = \begin{pmatrix} A \end{pmatrix} \begin{pmatrix} Dc \\ Dm \\ Dy \end{pmatrix} \quad (3); \qquad \begin{pmatrix} Dc \\ Dm \\ Dy \end{pmatrix} = \begin{pmatrix} A^{-1} \end{pmatrix} \begin{pmatrix} Dr \\ Dy \\ Db \end{pmatrix} \qquad (4)$$

The analytical density of each layer can be estimated from measured integral densities by using Eg.(4).

Fig. 2, shows the spectral density curves of the three dyes for the *IR*-color film.

From the data, matrixes (A) and (A^{-1}) can be calculated as follows :

$$(A) = \begin{pmatrix} 1.000 & 0.072 & 0.000 \\ 0.173 & 1.000 & 0.040 \\ 0.048 & 0.160 & 1.000 \end{pmatrix} ; \ (A^{-1}) = \begin{pmatrix} 1.012 & -0.073 & 0.002 \\ 0.174 & 1.019 & 0.040 \\ 0.020 & -0.159 & 1.006 \end{pmatrix}$$

4. THE CORRECTION OF INTER-IMAGE EFFECT

The development of dye in each layer of the multi-layer film, give some effects on development of dyes in other layers. This is known as the inter-image effect.

In the case of two layer film, as an example shown in Fig.3, the developing process for a part of the lower layer under highly exposed upper layer is inhibited more than for the other part under lower exposed upper layer due to the fatigue of developing agents. So, the density distribution lower layer is not uniform even if uniform exposure is given for the lower layer.

The amount of inter-image effect ΔD of another layer, due to the dye yield of one layer, ΔD, are given as follows :

$$\Delta d = K \Delta D \tag{5}$$

where K is a gradient of inter - image effect as the infra-red color film has three sensitive layer, the dye yield in one layer give the inter-image effects to the other two layers. So, analytical densities of dyes which are measured, Dc, Dm, and Dy are given as follows :

$$\begin{aligned} Dc &= kcc\, D'c + kcm\, D'm + kcy\, D'y \\ Dm &= kmc\, D'c + kmm\, D'm + kmy\, D'y \\ Dy &= kyc\, D'c + kym\, D'm + kyy\, D'y \end{aligned} \tag{6}$$

where Dc, Dm, and Dy are the analytical densities without the inter-image effects Kij is the gradient of the inter-image effects of i layer to j layer. and i,j are c, m, y.

Eg.(6) is also expressed as Eg.(7) and Eg. (8) :

$$\begin{pmatrix} Dc \\ Dm \\ Dy \end{pmatrix} = \begin{pmatrix} II \end{pmatrix} \begin{pmatrix} D'c \\ D'm \\ D'y \end{pmatrix} \quad (7) \; ; \qquad \begin{pmatrix} D'c \\ D'm \\ D'y \end{pmatrix} = \begin{pmatrix} II^{-1} \end{pmatrix} \begin{pmatrix} Dc \\ Dm \\ Dy \end{pmatrix} \tag{8}$$

From equation 8, true dye density analytical generated by exposure in each layer can be estimated from measured dye density. According to the measurement the gradient coefficients of the inter-image effect were given as follows :

$$\begin{pmatrix} II \end{pmatrix} = \begin{pmatrix} 1.000 & 0.036 & 0.054 \\ 0.002 & 1.000 & 0.000 \\ 0.060 & 0.041 & 1.000 \end{pmatrix} \quad (9) \; ; \quad \begin{pmatrix} II^{-1} \end{pmatrix} = \begin{pmatrix} 1.003 & 0.059 & 0.039 \\ 0.060 & 1.004 & 0.043 \\ 0.000 & 0.000 & 1.000 \end{pmatrix} \tag{10}$$

5. CORRECTION OF DIFFERENT CHARACTERISTIC CURVES OF THREE LAYERS

The relationship between dye density and exposure is given by characteristic curve, or D-H curve. By using this curves, the effective exposure in each layer can be estimated from dye density. Each H-D curve of the layer or an infra-red color film is different and non-linear. The densities H-D curve are generally given by the integrated densities with red, green and blue filters. So, in order to estimate the exposure, it is needed to obtain the H-D curves expressed in the analytical density. In Fig. 4, shows the H-D curve used in this study, and D-H curves expressed in analytical density is shown in Fig. 6, calculated from Eg.(4)

As seen in this figure, each H-D curve is different one another and has non-linear. Therefore, the H-D curves are approximated by polynomial equations as follows :

$$\begin{aligned} ED_{IR} &= F^{-1}_{IR}\ (D'_c) \\ ED_R &= F^{-1}_{R}\ (D'_m) \\ ED_G &= F^{-1}_{G}\ (D'_y) \end{aligned} \qquad (11)$$

Where IR, R, and G are the polynomials approximating D-H curves for infra-red sensitive cyan layer, red sensitive magenta layer and green sensitive yellow layer, ED_{IR}, ED_R, ED_G are relative exposures for each layers, and D'_c, D'_m , D'_y are analytical dye densities for each layer. The amount of dye in a color film is proportional to the analytical densities of dyes.

6. CORRECTION OF DIFFERENT SPECTRAL SENSITIVITIES OF EACH THREE LAYERS

Spectral sensitivity curves of each sensitive layers of an infra-red color film are overlapped one another, as shown in Fig. 5. Suppose the case of 650 mm monochromatic light, this light exposes the infra-red sensitive layer, and results in as if there exists infra-red light. Therefore, the overlapping of the spectral sensitivity should be corrected in order to estimate the amount of the incident radiant energy for each spectral band or layer. The amount of the exposure for each layer is proportional to the exposure time and the mean value of input energy.

$$DE_i = t \frac{\int_{500}^{900} I_\lambda \, Si \, d\lambda}{\int_{500}^{900} Si \, d\lambda} \qquad i = IR,\ R,\ G \qquad (12)$$

Where Si is the spectral sensitivity of i-th layer, i = IR, R, G, and I_λ is the

spectral irradiance of input radiation.

Here, let's devide the spectral distribution of the input radiation into three band regions (500 - 600 nm), (600 - 700 nm), (700 - 900 nm), which are not overlapped one another. And let's be the mean value of input energy within each wave length band as equivalent spectral distribution, I_{IR}, I_R, and I_G, then, equation (12) can be written as follows :

$$DEi = t \frac{\int_{500}^{900} \bar{I}_{IR}\, Si\, d\lambda . t \int_{600}^{700} \bar{I}_R\, Si\, d\lambda . t \int_{500}^{600} \bar{I}_G\, Si\, d\lambda}{\int_{500}^{900} Si\, d\lambda} \tag{13}$$

this reduced to,

$$\begin{aligned} DE_{IR} &= S_{11}\, t\, .\, \bar{I}_{IR} + S_{12}\, t\, .\, \bar{I}_R + S_{13}\, t\, .\, \bar{I}_G \\ DE_R &= S_{21}\, t\, .\, \bar{I}_{IR} + S_{22}\, t\, .\, \bar{I}_R + S_{23}\, t\, .\, \bar{I}_G \\ DE_G &= S_{31}\, t\, .\, \bar{I}_{IR} + S_{32}\, t\, .\, \bar{I}_R + S_{33}\, t\, .\, \bar{I}_G \end{aligned} \tag{14}$$

where,

$$S_{11} = \frac{\int_{700}^{900} S_{IR}\, d\lambda}{\int_{500}^{900} S_{IR}\, d\lambda}, \qquad S_{12} = \frac{\int_{600}^{700} S_{IR}\, d\lambda}{\int_{500}^{900} S_{IR}\, d\lambda}, \qquad S_{13} = \frac{\int_{500}^{600} S_{IR}\, d\lambda}{\int_{500}^{900} S_{IR}\, d\lambda}$$

these S's are related to the only film sensitivities.

$$\begin{pmatrix} DE_{IR} \\ DE_R \\ DE_G \end{pmatrix} = \begin{pmatrix} S \end{pmatrix} \begin{pmatrix} t\bar{I}_{IR} \\ t\bar{I}_R \\ t\bar{I}_G \end{pmatrix} \quad (15); \qquad \begin{pmatrix} t\bar{I}_{IR} \\ t\bar{I}_R \\ t\bar{I}_G \end{pmatrix} = \begin{pmatrix} S^{-1} \end{pmatrix} \begin{pmatrix} DE_{IR} \\ DE_R \\ DE_G \end{pmatrix} \tag{16}$$

From equation (16), the irradiance of each spectral band can be obtained. For Infra-red color film, these S's from the data for Kodak infra-red color film are calculated as follows :

$$\begin{pmatrix} S \end{pmatrix} = \begin{pmatrix} 0.593 & 0.268 & 0.136 \\ 0.000 & 0.871 & 0.126 \\ 0.000 & 0.000 & 1.000 \end{pmatrix} \quad (17); \qquad \begin{pmatrix} S^{-1} \end{pmatrix} = \begin{pmatrix} 1.709 & 0.505 & -0.189 \\ -0.020 & 1.197 & -0.166 \\ -0.000 & 0.000 & 1.000 \end{pmatrix} \tag{18}$$

7. CORRECTION OF CAMERA FLARE AND PATH RADIANCE IN THE ATMOSPHERE

Camera flare is ordinary superposed additively and unformly to the whole image and average irradiance at the image plane will be increased. Here, as a correction procedure, we assume that the flare is proportional to the average densities of the whole image :

$$F\alpha = \alpha \frac{1}{3r} \sum_{j=r,gb} \left(\sum_{i=1}^{n} 10^{-D_{ij}} \right) \tag{19}$$

Where D_{ij} is optical densities. In the remote sensing, the spectral reflectance of the objects, is more importance than the radiance of the objects.

Let's average the reflectance of an object within each of three bandregion, as shown in Fig. 6, and designate it as $\bar{\rho}i$ and the spectral energy distribution of illuminating light at ground level as $I_{G\lambda}$. Then, the input radiant energy each spectral band or layer is given as follows :

$$\bar{I}i = K \int_{700}^{900} (I_{G\lambda} \bar{\rho}i \, \tau d + \pi Lp) \tau_0 \, d\lambda \tag{20}$$

where, $\bar{\rho}i = \int_0 \rho\lambda d\lambda$ is an average reflectance and πLp is atmospheric path radiance which is generally, equivalent to flare, and τ_0 is one way transmittance of the atmosphere.

The spectral energy distribution of illuminating light at ground level, is easily changed by the climate conditions. When, we assume that the objects are illuminated by the sun light color temperature 5500 K° then,

$$\bar{\rho}_{IR} = K \frac{\bar{I}_{IR} - F\alpha}{\int_{700}^{900} I_{G\lambda} d\lambda} \; ; \; \bar{\rho}_R = K \frac{\bar{I}_R - F\alpha}{\int_{600}^{700} I_{G\lambda} d\lambda} \; ; \; \bar{\rho}_G = K \frac{\bar{I}_G - F\alpha}{\int_{500}^{600} I_{G\lambda} d\lambda} \tag{21}$$

From Eg.(21), the effective average reflectance can be derived.

8. EXPERIMENTAL RESULTS

A procedure to correct the radiometric distortions of infra-red color film image is shown in Fig. 7. The procedure is just inverse one for light incidence and exposure process.

This is due to the fact that the final data measured with an infra-red color film are integral density through red, green and blue filters.

Fig. 8, shows the flow chart of the correction programs. The film type used in this investigation was Kodak Aerochrome Infra-red film # 24218, and the test site was an agricultural area located in near Memuro city in Hokkaido, north part of Japan.

After exposure and development the photographs were scanned by a mechanical scanner with an aperture of 100 x 100 μ. The scanned data were sampled and converted into 12 bits form corresponding to the integral color density range of 0 ~ 5.0, and stored on a magnetic tape.

Fig. 9, shows uncorrected image displayed on a color CRT with 16 steps of grey tone. As seen in Fig. 9, the image shows rather bluish. At the same agricultural field located separately are displayed in different colors due to the $\cos^4$ law of lens system.

Fig. 10, shows the corrected image by using equations [4; 9; 11; 14; 19 ; 21] The corrected image turned to be more redish as a whole than the uncorrected image. It may be concluded that the non-uniform grey tone due to the $\cos^4$ law reduction is well decreased by the correction. The corrected image might have improvement in the performance of visual interpretation.

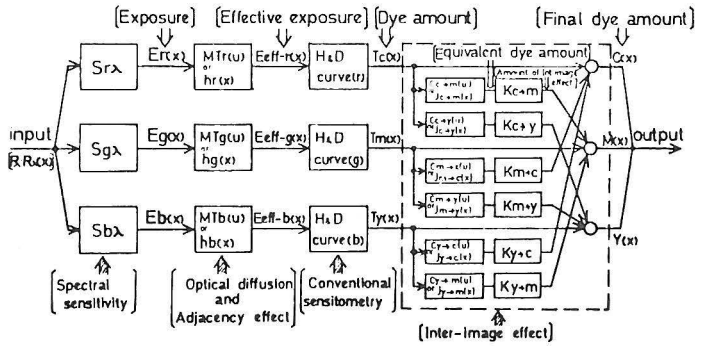
Finally, a supervised classification of agricultural area by a computer were applied to uncorrected and corrected images in order to compare the performances of qualitative classification. The spatial distributions of the infra-red, red, and green densities of an object can be expressed as an rotating ellipse, and characterized by the length of short and long axis of the ellipse and its volume.

In Table 1, the density distributions of soil and vegetations, such as beet and corn obtained by the correction are shown.
By the correction lengths of short and long axis and volume of the ellipse have become smaller and the dispersion of the distribution of each object has been much reduced. And the corrections seem to be useful to automatic-interpretation for remote sensed imageries.

CONCLUSION

Mathematical formulas, which predicate various radiometric distortions are derived, and then, corrections for these distortion are performed by a digital computer. Among the distortions, spectral sensitivity overlap of each sensitive layers of the color film, especially an infra - red sensitive cyan dye layer, of which spectral sensitivity extends to the visual region, has an unwanted effect on the resultant color of the IR-color film, and makes the color to be dull, and the inter-image effect has not so heavy effect.

On the other hand, $\cos^4$ distortion always known to have to be corrected.



Block diagram of color film model having the spatial freqeuncy responses.

Figure 1.

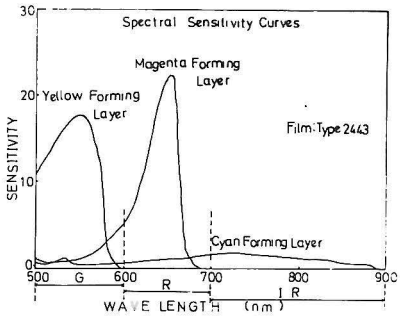


Figure 5.

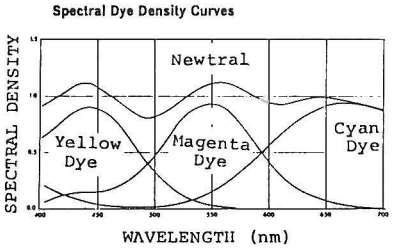
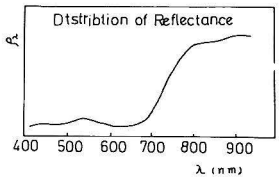


Figure 2



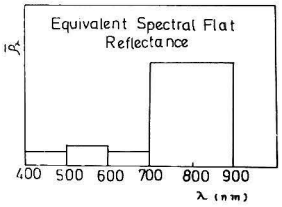


Figure 6

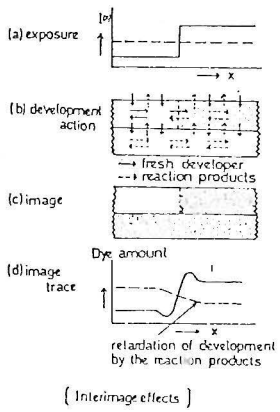


Figure 3.

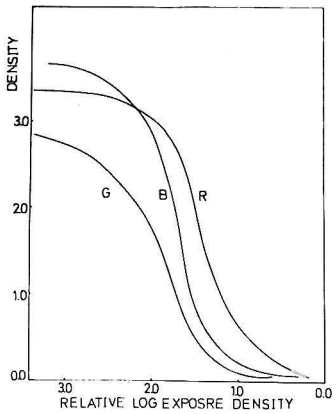


Figure 4.

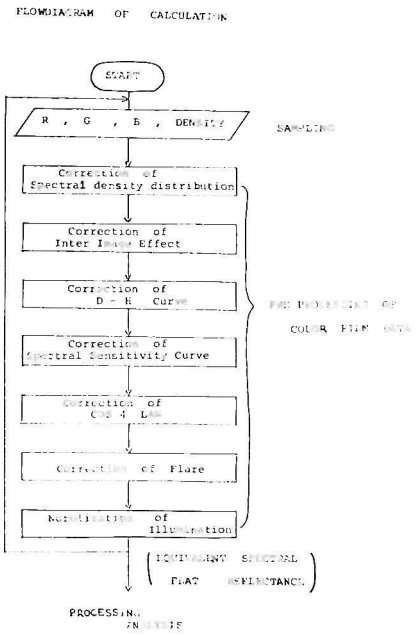


Figure 7

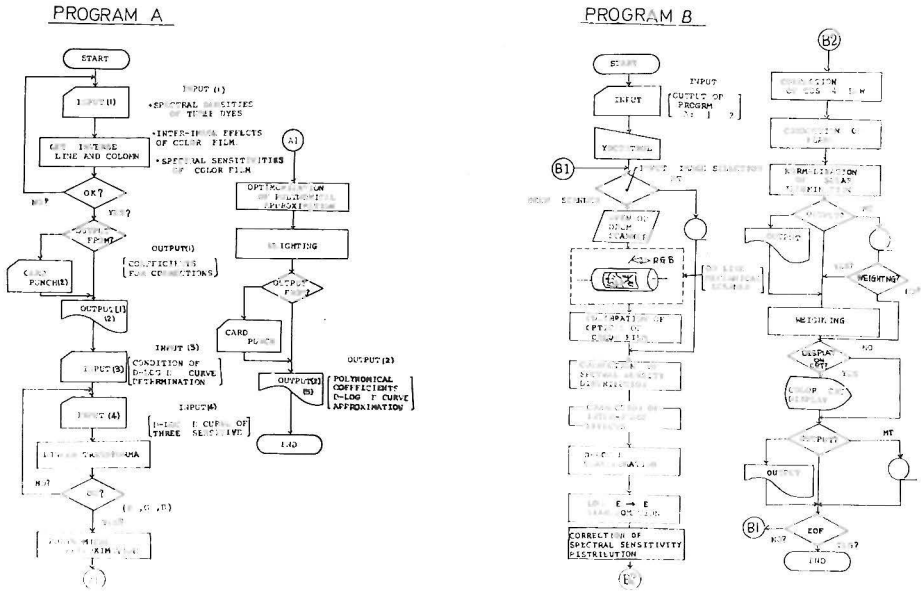


Figure 8.

Fig. 9

Fig. 10

TABLE I. DISCRIMINATION FUNCTION

CLASS		CENTER $\bar{C}$			MAJOR AXIS	MINOR AXIS	V
		R	G	B			
A beet (center part)	unprocessed	1.76	0.63	0.22	0.42	0.34	0.203
	processed	2.71	0.20	0.18	0.59	0.10	0.025
B corn (after harvest)	unprocessed	0.39	0.55	0.19	0.67	0.27	0.205
	processed	1.55	0.42	0.28	0.37	0.11	0.019
C beet (perphery part)	unprocessed	1.57	0.52	0.26	0.35	0.35	0.180
	processed	2.68	0.21	0.19	0.44	0.09	0.015
D bare soil (perphery part)	unprocessed	0.70	0.93	0.23	0.37	0.12	0.022
	processed	1.38	0.32	0.19	0.78	0.06	0.009