"ATMOSPHERIC" CORRECTION OF DIGITAL COLOUR IMAGES BASED ON LUMINANCE RATIO CONSIDERATION

H. Ziemann[a], D. Grohmann[b]

[a] FB3, Anhalt University of Applied Sciences, 06846 Dessau, Germany, hziemann@afg.hs-anhalt.de
[b] Gropius-Institute, 06846 Dessau, Germany, grohmann@afg.hs-anhalt.de

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ABSTRACT:

Colour images change their appearance with increasing flying height: they are affected by an increasing bluish tint. This phenomenon is primarily the result of Rayleigh scattering. Considerations concerning a correction of the atmospheric effect lead to the investigation reported herein. The chosen approach originating from the areas of reprographic technique and photographic tone reproduction. Atmospheric data are not required.

1. INTRODUCTION

Optical images formed with lenses always appear to have less contrast than the scenes being photographed due to the effect of flare light. Flare light is non-image-forming light. Atmospheric flare is dependent upon wavelength and object distance and varies therefore for different channels of a multi-spectral camera and for flying height.

This paper presents reviews of photographic and atmospheric flare, introduces the basic concepts of tone reproduction and suggests a method for the atmospheric correction for digital colour images which does not require atmospheric data.

2. PHOTOGRAPHIC FLARE

Flare light is non-image-forming light. It occurs in the image plane as a uniform veil, provides an approximately uniform illuminance over the entire image area, increases the illuminance of every point on the camera image and thus results in a loss of image contrast. Some of the more important factors influencing the amount of camera flare light are the object characteristics, the lighting conditions, lens and camera design (causing e.g. single or multiple reflections from the lens surfaces, diaphragm, shutter blades and additional interior surfaces of the camera) and dust and dirt within the camera. Of theses factors, the first two have the greatest influence.

The amount of flare light can vary greatly with a given lens depending upon the distribution of light and dark tones in the scene and the lighting. When a camera is aimed at an object, the *object luminances L* and therefore the physical values of light reaching the lens represent the initial image input data. If the luminance of the lightest diffuse highlight is divided by the luminance of the darkest shadow with detail, the resulting value is termed the *luminance ratio* ($LR = L_{max}/ L_{min}$).

The *image illuminance E* consists of two parts: image forming light E' and flare light ΔE:

$$E = E' + \Delta E.$$

It will here be assumed that the illuminance E' for the image forming light is equals to the luminance L. Flare light can be specified in various ways: as *illuminane ratio*

$$ER = E_{max}/E_{min},$$

as a percentage of the maximum image illuminance

$$100 \times E/E_{max},$$

as a flare curve for tone reproduction considerations and as a *flare factor* (FF):

$$FF = LR / ER.$$

The addition of flare light causes the illuminance ratio ER to always be smaller than the luminance ratio LR.

It is perhaps obvious that the reduction in image contrast is the result of different percentage increases at the opposite ends of the illuminance scale; for example, the additional unit of flare light in the shadows may provide a doubling of the light in that region, while the additional unit of light in the highlights presents only a very small percentage of increase. This will be shown in the following table; object luminances at equal logarithmic spacing were chosen in view of a later graphical presentation of the flare factor:

The addition of flare light causes the illuminance ratio ER to always be smaller than the luminance ratio LR:

$$LR = L_{max}/L_{min} = 1000/ 1 = 1000$$

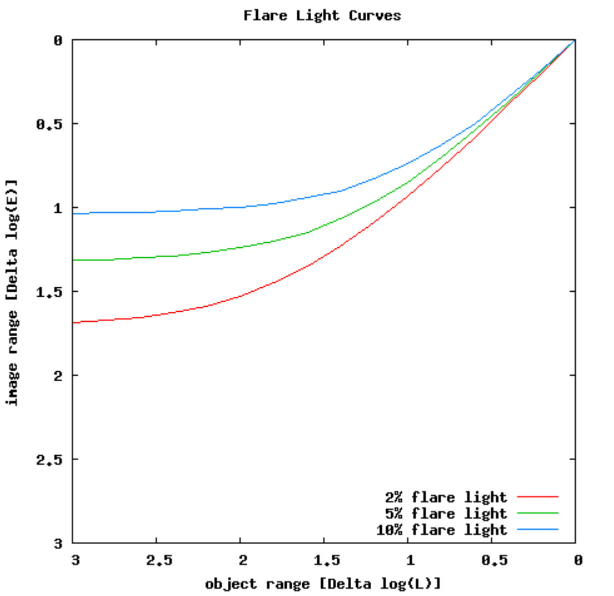
ΔlogL	L [%]	L_{max}/L	L+2%	E_{max}/E	$\Delta logE_2$	L+5%	E_{max}/E	$\Delta logE_5$	L+10%	E_{max}/E	$\Delta logE_{10}$
3.0	0.10	1000	2.10	47.6	1.69	5.10	19.6	1.31	10.10	9.9	1.04
2.8	0.16		2.16		1.67	5.16		1.31	10.16		1.03
2.6	0.25		2.25		1.66	5.25		1.30	10.25		1.03
2.4	0.40		2.40		1.63	5.40		1.29	10.40		1.02
2.2	0.63		2.63		1.59	5.63		1.27	10.63		1.01
2.0	1.00	100	3.00	33.3	1.53	6.00	16.7	1.24	11.00	9.1	1.00
1.8	1.58		3.58		1.45	6.58		1.20	11.58		0.98
1.6	2.51		4.51		1.35	7.51		1.15	12.51		0.94
1.4	3.98		5.98		1.23	8.98		1.07	13.98		0.90
1.2	6.31		8.31		1.09	11.31		0.97	16.31		0.83
1.0	10.00	10	12.00	8.3	0.93	15.00	6.7	0.85	20.00	5.0	0.74
0.8	15.85		17.85		0.76	20.85		0.70	25.85		0.63
0.6	25.12		27.12		0.58	30.12		0.54	35.12		0.50
0.4	39.81		41.81		0.39	44.81		0.37	49.81		0.34
0.2	63.10		65.10		0.20	68.10		0.19	73.10		0.18
0.0	100.00	1	102.00	1.0	0.00	105.00	1.0	0.00	110.00	0.9	0.00

$$ER_{2\%} = E_{max}/E_{min} = 102.0/2.1 = 47.6$$
$$ER_{5\%} = E_{max}/E_{min} = 105.0/5.1 = 19.6$$
$$ER_{10\%} = E_{max}/E_{min} = 110.0/10.1 = 9.9$$

For $L = 0.1\times L_{max}$ one obtains with the data used to derive the foregoing table

$$100\times\Delta E_{2\%}/E_{max} = 2 / 102 = 2.0\ \%$$
$$100\times\Delta E_{5\%}/E_{max} = 5 / 105 = 4.8\ \%$$
$$100\times\Delta E_{10\%}/E_{max} = 10 / 110 = 9{,}1\ \%$$

The values presented in the foregoing table can also be graphically presented as so-called flare light curves using logarithmic object-range values as abscissa values and logarithmic image-range values as ordinate values:



Flare light can be expressed as a *flare factor* (FF) which is derived by dividing LR by ER:

$$FF_{2\%} = LR / ER_{2\%} = 1000.0 / 47.6 = 21$$
$$FF_{5\%} = LR / ER_{5\%} = 1000.0 / 19.6 = 51$$
$$FF_{10\%} = LR / ER_{10\%} = 1000.0 / 9.9 = 101$$

3. TONE REPRODUCTION CONSIDERATIONS

The tone-reproduction properties of photographic emulsions are described using the so-called characteristic curve, a presentation of the functional relationship between input illuminance and the resulting photographic image. If the conditions of measurement used to obtain the data simulate the conditions of use well, the characteristic curve provides an excellent description of the tone-rendering properties of photographic emulsions.

When determining the tone-reproduction properties of a photographic system, there are objective and subjective aspects to be considered. In the objective phase, measurements of light reflected from the object are compared to the measurement of light reflected or transmitted by the photographic reproduction. These reflected-light readings (scientifically called luminances) can be measured accurately with a photoelectric meter having a relative spectral response equivalent to that of an "average" human eye. The logarithms of these luminances are then plotted against reflection or transmission densities in the photographic reproduction, and the resulting plot is identified as the objective tone-reproduction curve.

The perception of lightness of a subject or image area corresponds roughly to its luminance; but unlike luminance, lightness is not directly measurable. It involves also physiological and psychological factors. An area of constant luminance can appear to change in lightness for several reasons, for example the adaptation to different light levels. A graph showing the relationship between perceived lightness and measured luminances would be called a subjective tone-reproduction curve.

A tone-reproduction diagram combines several processes of an imaging chain, e.g. for a photographic process the subject, the atmosphere, film exposure and development and the final photographic image and enables a comparison of the input luminances to the densities of the photographic image. If objective tone-reproduction curves are known for the final image, the different processes can possible modified to achieve that curve; for example, the contrast of monochrome photography can be increased by using a suitable cut-off filter for shorter wavelengths.

Digital photography uses CCD's instead of photographic emulsions as a recording medium. The response is no longer logarithmic, however the possibility to work with maximum and minimum luminances remains although the shape of the tone-reproduction curve is no longer meaningful. One could consider to convert the digital images to density images first and then apply tone-reproduction considerations more fully; however, this has not been done in the course of this investigation.

4. ATMOSPHERIC FLARE

In addition to camera flare, atmospheric flare must also be considered. It is thought to be caused primarily by Rayleigh scattering,

$$\beta = (2\pi^2/N\lambda^4)[n(\lambda)-1]^2(1+\cos^2\theta)$$

where N is the number of molecules per unit volume, λ the wavelength, $n(\lambda)$ the spectrally dependent refractive index of the molecules and θ the angle between the incident and the scattered flux. For operating heights of interest in photogrammetry N (which is a function of h) can be considered constant, hence

$$\beta \approx (2\pi^2/\lambda^4)[n(\lambda)-1]^2(1+\cos^2\theta) \sim 1/\lambda^4.$$

Sine $n(\lambda)$ decreases with increasing flying height β is not independent of h.

The refractive index of air, minus one, is proportional to the density of air. At 600nm, the equation for the refractive index of dry air as a function of air density is:

$$n_i = 1.0 + 0.0002763\ (\delta_i/\delta_o)$$

where n_i is the refractive index for air of density δ_I, and δ_o is the density of air at sea level. The numerical coefficient will change slightly for other visible wavelengths.

Assuming availability of the spectral response characteristics for the four multi-spectral channels, a representative wavelength can be derived for each channel, for example as weighted mean value. These values may be as follows:

$$\lambda_b = 477\text{nm},\ \lambda_g = 558\text{ nm},\ \lambda_r = 636\text{ nm},\ \lambda_{nir} = 756\text{ nm}.$$

These λ yield relative Rayleigh scattering values $\beta \sim 1/\lambda^4$of

$$\beta_b = 19.3,\ \beta_g = 10.3,\ \beta_r = 6.1,\ \beta_{nir} = 3.1.$$

It is seen that the scattering is significantly larger for blue, causing the known effect of the surface of the Earth becoming bluer with increasing flying height. This effect has been counteracted in monochrome aerial photography by using yellow filters.

5. LUMINANCE RATIO AND FLYING HEIGHT

Digital image data for B, G, R and NIR channels are available for the same area taken from three different flying heights: $h_A = 2h_B = 4h_C$. The histogram values are understood to be relatively scaled illuminance values. The histograms of the partial images are used to carry out the following calculations. First, the maximum and minimum illuminances needed to calculate the illuminance ratios ER_i are determined. In order to check on the effect of noise, thresholds of 5%, 3.5% and 2% of the maximum and minimum histogram values were tested and that of 5% introduced.

5%	nir	NIR	r	R	g	G	b	B	H [m]
C	279	2537	116	913	208	1166	213	645	1500
B	234	1755	118	604	238	821	276	528	3000
AB	309	1483	135	376	281	603	350	485	6000
		ER_{nir}		ER_r		ER_g		ER_b	
C		9.09		7.87		5.61		3.03	
B		5.42		5.12		3.45		1.91	
AB		4.80		2.79		2.15		1.39	

3.5%	n	N	r	R	g	G	b	B	H[m]
C	255	2592	109	964	196	1224	222	677	1500
B	326	1815	113	723	225	944	258	559	3000
AB	309	1483	126	529	259	753	325	490	6000
		ER_{nir}		ER_r		ER_g		ER_b	
C		10.16		8.84		6.24		3.05	
B		5.57		6.40		4.20		2.17	
AB		4.80		4.20		2.91		1.51	

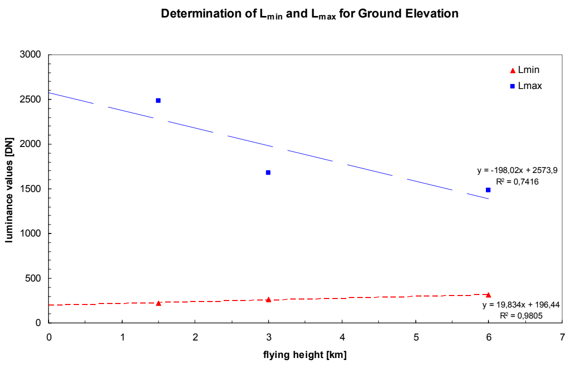
2%	nir	NIR	r	R	g	G	b	B	H [m]
C	236	2676	104	1213	192	1480	218	848	1500
B	292	1888	110	806	216	1039	255	636	3000
AB	309	1483	123	613	255	857	323	578	6000
		ER_{nir}		ER_r		ER_g		ER_b	
C		11.34		11.66		7.71		3.89	
B		6.47		7.33		4.81		2.49	
AB		4.80		4.98		3.36		1.79	

As atmospheric flare can be expected to be smallest for the NIR images, an analysis of the NIR data was carried out first aiming at the derivation of a functional relationship between luminance ratio LR and flying height h under the initial assumption that the data are unaffected by flare light ΔE; hence $E_{max} \approx L_{max}$ and $E_{min} \approx L_{min}$. Since the luminance range proved to be dependent upon h, it was next attempted to derive a functional relationships L_{min}=F(h, x),

$$L_{min} = 200\ h^x,\ \ x = 1/4$$

and L_{max}=L_{min}+dE with dE=E_{max}-E_{min}. The values for L_{min} can be approximated by a straight line. In order to avoid unreasonably large values L_{max} for h approaching zero L_{max} was also replaced by a straight regression line; see the figure on top of the following column.

The resulting L_{max} = 2574 and L_{min} = 196 were used to determine the initial luminance ratio for ground elevation LR_0 = 13.1. Afterwards, the luminance ratios LR_i for the different flying heights are derived from the two lines representing L_{min} and L_{ma}, and the factors LR_0/LR_i determined. These factors counteract as multiplication factors the decrease of the luminance ratio with increasing flying height:



h[km]	$h^{1/4}$	L_{min}	dL	L_{max}	LR	LR_0/LR
0	0	196	2378	2574	13.1	1.00
1.5	1.1067	221	2258	2479	11.2	1.17
3	1.3161	263	1413	1676	6.4	2.06
6	1.5651	313	1174	1487	4.8	2.76

Using the flare light equation with LR_0 = 13.1 (from the foregoing table) and $L_{max} \approx E_{max}$ (see values given in the table of the 5% histogram threshold values), ΔE values are calculated for the three other channels. Using the derived ΔE one derives:

$$L_{max}' = LR_0/LR \times dE - \Delta E + E_{min}$$

In order to avoid negative values for L_{max}', the condition L_{max}' $\geq E_{min}$ was introduced. Using L_{max}' one obtains L_{min}' as:

$$L_{min}' = L_{max}' - LR_0/LR \times dE$$

Assuming that the object characteristics are independent of the flying height, the L_{min}‘ for the flying heights of 3 and 6 km were made identical to that for 1.5 km. The L_{max}‘ were changed accordingly and new LR computed.

The three luminance range values for each colour obtained for the three flying heights were averaged for the next computational step: LR_r= 16.42, LR_g= 20.16 and LR_b= 413.17. These values and the L_{max} values from step 1 were then used to compute improved flare light values:

$$\Delta E = L_{max}(1-ER/LR_{r/g/b})/(ER-1)$$

and new values for L_{min}', L_{max}', L_{min}, L_{max} and LR using the same equations as before.

Histogramms for the original and the recalculated photographs and a visual comparison do the original and the recalculated photographs show in particular for the two larger flying heights a significant colour improvement.

6. SUMMARY AND CONCLUSIONS

After correction, the images from the different flying heights look similar, showing that the reported approach to "atmospheric" correction works. The process requires additional verification using different sets of test images which have not yet become available to us.

The investigation led to a proprietary correction process in several stages:

- *for all images:* The histograms for all partial images are determined and searched for threshold values, e.g. at 5% minimum and maximum value, to eliminated unwanted dark and light extreme values ("noise").
- *for NIR images only:* the following values are derived from the histogram values understood as "scaled" luminance values: L_{min}, L_{max} and LR_i.

- *for R, G, B images:* calculation of "normalized" L_{min} and L_{max}.

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All image related computations were carried out with Geomatica V 9.1.6.