CORRECTION OF THE LIGHT-FALL-OFF IN PHOTOGRAPHS BY MEANS OF DIGITAL STATISTICAL METHODS

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Abstract

Frame camera photographs contents more information than scanner imagery due to their higher spatial resolution. Moreover their geometrical conditions are especially simple. On the other hand their great disadvantage is the light-fall-off of the objective near the image edges. This disturbance must be corrected before further digital evaluation, e. g. multispectral classification.
The paper presents statistical methods for this correction:

- low pass filtering
- approximation by two-dimensional polynomials

Results of both techniques are demonstrated and compared with the analytical cos-approach.

Introduction

One part of the research activities of the Institute for Photogrammetry and Engineering Surveys of Hannover University is tidal land mapping according to digital multispectral classification methods (/2/,/3/,/5/). Thereby image data of digital recording sensors (e.g. LANDSAT) are in use as well as digitized photographs from frame cameras (/5/).
One specific disadvantage of the latter images is the light-fall-off of the camera lens, which can be very inconvenient for classification at the image edges (/4/,/7/).
One way of digital image correction is, to describe light-fall-off by a function, which requires the knowledge of lens characteristics (/1/). As this method starts from ideal conditions, namely a central radial symmetry of the light-fall-off, actual taking conditions with regard to the position of the sun and the inclination of the camera lens are not considered.
Much more efficient are those methods, which depend only on image statistics (/6/). The paper presents two of these methods and their results, shown on aerial photographs of the tidal lands of the Fresian North Sea coast:

- Description of light-fall-off by low-pass-filtering
- Approximation of light-fall-off by polynomials of second and third degree.

It can be shown, that in small subimages even a simple linear fit is sufficient to achieve high classification accuracies (/3/).

Fundamentals

Due to geometrical reasons image intensity decreases continuously from the principal point to the edges. This so-called 'natural light-fall-off' is described by the Lambert's $\cos^4\alpha$ -law. 'α' is the angle between the principal ray of the image element (x,y) and the lens axis (/1/). Especially super wide-angled camera lenses produce great image angles (8.5/23 : 135 gon). Therefore the light-fall-off appears extremely strong. Lambert's law of light-fall-off can only be applied to single lenses, but not to lens systems of photographic cameras. By improvements in construction of the optical systems, the light-fall-off can partly be reduced to $\cos^{2.5}\alpha$ (/6/).

Fig. 1

Light power of the camera objective ZEISS-PLEOGON relative to the image centre

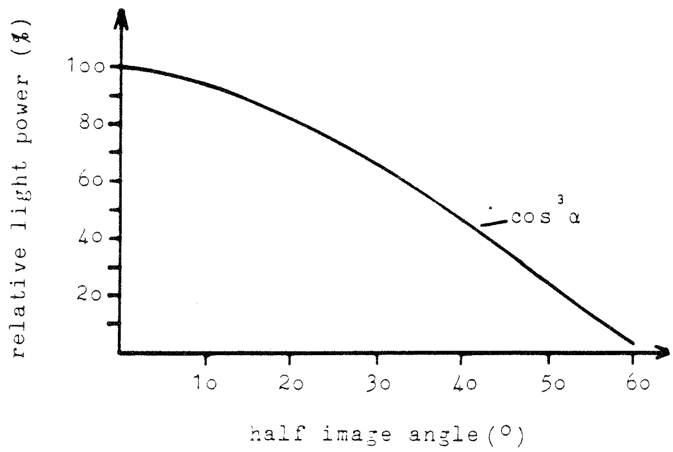


Fig. 1 shows as example the light power of the camera objective ZEISS-PLEOGON ($\cos^3\alpha$) relative to the image centre.
Fig. 2 shows the light-fall-off in a terrestrial photograph of a $BaSO_4$ covered plate (/1/). The photograph was taken under following ideal conditions :

- surface of the object has diffuse reflex characteristics
- planes of photograph and object are parallel to each other
- sun stands behind the plate outside the visual field of the camera (no shadows)

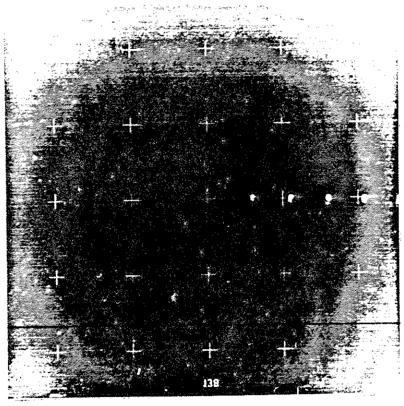


Fig. 2

Light-fall-off in a terrestrial photograph of a $BaSO_4$ covered plate

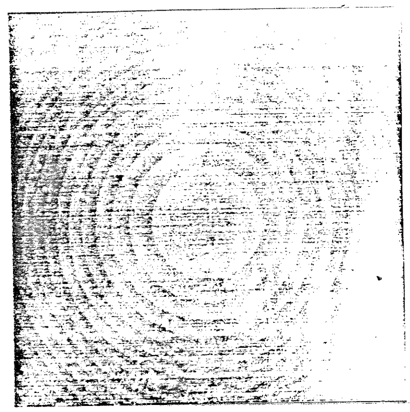


Fig. 3

Corrected by Lambert's law

The light-fall-off in this photograph is symmetrical with its centre at the principal point. For latter visual interpretations a positive-negative change and a histogramm equalization of the digitized image has been performed. Fig. 3 shows the histogram equalized picture corrected analytically according to Lambert's law. One can clearly realize, that the assumption of radial symmetrie of light-fall-off is reasonable.

Light-fall-off is a radial symmetrical disturbance, which is principal caused by the frame camera. On the other hand in reality light-fall-off is superimposed by other disturbing influences. So differences in brightness, especially caused by divergence of the taking- and illumination direction (sun position) to 0^{o}-zenith angle can appear. Fig. 4 demonstrates this on a super wide-angled photograph taken by frame camera of the North Fresian tidal lands. As camera objective a ZEISS-PLEOGON was used :

Fig. 4

Light-fall-off in an aerial photograph, showing the North Fresian tidal lands

Because of the inclination of the camera and the position of the sun in south-east ($11^{\underline{00}}$ h), the centre of light-fall-off is displaced to the north.
Compared to the 'ideal' photograph (fig. 2) it can be seen that recording and environmental conditions must be considered for the purpose of light-fall-off correction. So functions, which depends on image statistics must be applied.

Statistical techniques for light-fall-off correction

Entire image correction

In the following two different techniques for entire image correction are presented and discussed. One method consists of image filtering at certain frequencies (/7/). The light-fall-off is to seperate from the real information in the photograph. This can be achieved by low-pass-filtering. The light-fall-off is associated with low frequencies (one cycle/image). Light-fall-off representation can be obtained by extreme low-pass-filtering removing all high frequency image information. This estimated light-fall-off can be subtracted from the original photograph. By the use of an inverse high-pass-filter the photograph can directly be corrected. In the following the filter procedures are performed directly in the frequency domain (/7/).

Fig. 5

Result of a low-pass-filtering, applied to the aerial photograph

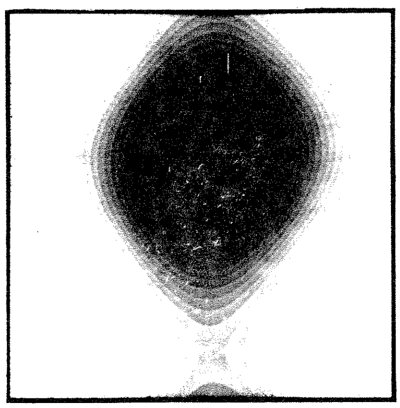


Fig. 5 shows the result of a low-pass-filtering, applied to the aerial photograph (fig.4). Frequencies below 1 cycle/image are preserved, beyond 2 cycles are partly lost, whereas higher frequencies are completely supressed.
One disadvantage of low-pass-filtering is, that a correct separation of image information and image disturbance is impossible as soon as both appear in the same frequency range.

Annother correction method, derived from image statistics is to approximate the light-fall-off by a two-dimensional polynomial of second or third degree.

$$GV = a_1 + a_2x + a_3y + a_4x^2 + a_5xy + a_6y^2 (+ a_7x^3 + a_8x^2y + a_9xy^2 + a_{10}y^3)$$

To estimate the polynomial coefficients, the coordinates of reference points are measured in the image. These points should belong to one object class and should be distributed over the whole image. These coordinates serve as centres for square blocks, in which the mean grey values are determined. Using least-square fit, these mean grey values serve as input for the polynomial estimation. After coefficient computation, the two-dimensional polynomial is generated by interpolation all over the image. The light-fall-off is represented as a digital image. The correction can be performed by subtracting it from the original image.

Approach of light-fall-off by 2-nd degree polynomials
with reference points from different object classes

Fig. 6

Object class
'meadow'

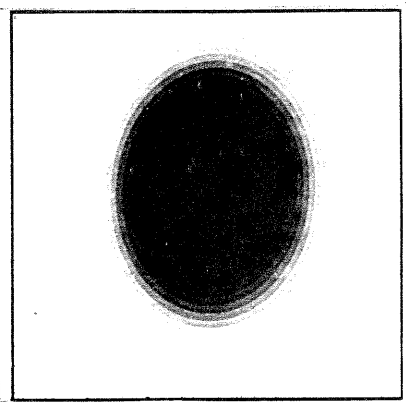


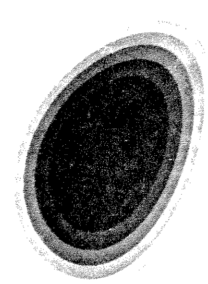
Fig. 7

Object class
'water'

Fig. 6 shows the light-fall-off of figure 4 as a two-dimensional polynomial of second degree. The reference points (35) are measured in the object-class 'meadow'. The light-fall-off in fig. 7 was estimated with reference points in the object-class 'water'. The different positions of the light-fall-off centres result from the different distribution of the object-classes in the image. The object class 'meadow' for instance can be found mainly in the north.

Fig. 8

Approach of light-fall-off
by a 3-rd degree polynomial
with reference points of
the object class 'water'



No significant improvement can be obtained by applying polynomials of higher degree. Fig. 8 shows an example of third degree approximation according to the object class 'water'.
It is evident, that image correction by polynomials is most efficient in that object class, where the reference points are measured in (/7/).

Fig. 9

Density sliced original image

Fig. 10

Corrected image according to low-pass-filtering

Fig. 11

Corrected image according to polynomial approximation (2nd degree/'meadow')

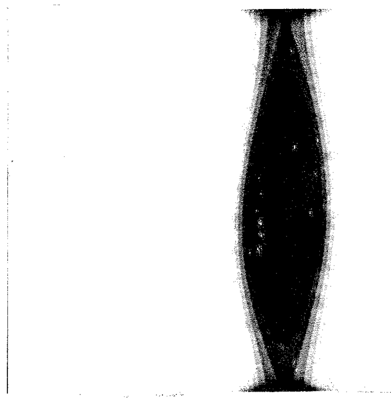
The effects of the applied correction methods are demonstrated in fig. 9-11. Fig. 9 shows the density sliced original image. Fig. 10 and 11 present the corrected images according to low-pass-filtering (fig. 10) and polynomial approximation with the object class 'meadow' (fig. 11). Because the correction by a polynomial approach is efficient mainly in the reference-point-class, the local independent low-pass-filtering seems to be superior for correcting entire images. If the image shall be evaluated with emphasis on a special object class, the polynomial approximation shall be applied.

Fig. 12

Uncorrected subimage

Fig. 13

Low-pass-filtered subimage



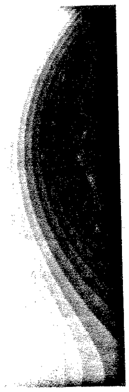


Fig. 14

Polynomial approximation of light-fall-off (3. degree)

Fig. 15

Linear correction of the subimage

Table 1 : Classification accuracy in check areas

class	classified as 1		2		3		4+)	
	o	c	o	c	o	c	o	c
1	85.2	99.5	0.0	0.0	0.0	0.0	14.8	0.5
2	1.3	0.0	10.0	95.7	88.8	4.3	0.0	0.0
3	0.0	0.0	69.7	1.1	2.6	98.9	27.6	0.0

+) 4 = unclassified

o = original image

c = corrected image

Subimage correction

If light-fall-off correction shall be applied to subimages, the results are different from those, obtainted from entire image enhancement.
An example is given in fig. 12, showing a histogram equalized subimage of an aerial photograph from East Fresian tidal lands. The photograph was taken by aircraft with a flying height of 600 m, containing only tidal land information. One can see from east to west a continuous growing of light-fall-off. Fig. 13 is the result of a low-pass-filtering of this image. Frequencies beyond one cycle/image are supressed. Several minima and maxima of different magnitude, not according to the real light-fall-off in the photograph can be seen. Moreover the grey-values in the left and the right image edges are equal. This effect is caused by the Fourier-analysis, which is computed before each filtering, and which produces periodicity in the light-fall-off images (/8/). So low pass filtering in the frequency domain can efficiently be applied only in entire images.
Fig. 14 shows the light-fall-off of the subimage, approximated with a polynomial of third degree (56 reference points). Because tidal land is predominant in this photograph, the reference points could be easy measured and the representation of the light-fall-off corresponds to the reality.
Fig. 14 demonstrates, that a simple linear algorithm can be sufficient for image correction. Fig. 14 suggests a linear estimation, depending only on the column position 'y' :

$$GV\ (x,y) = ay + b$$

A linear regression of the mean grey value versus the column number allows an easy and fast estimation of 'a' and 'b' without the need of point measurements. The trend of the computed light-fall-off is subtracted from the original image. Fig. 15 shows the result of this correction.
The efficiency of a linear correction can be proved by supervised multispectral classification (/3/). The accuracy of the classification performance is measured in training areas and in so-called 'check areas'. The latter ones are not used for the estimation of object class statistics and allow therefore independent testing of the achieved results. Table 1 shows the classification accuracy in the check areas before and after linear correction. Classes to be detected are 'dry mud flat' (1), 'moist mud flat' (2) and 'diatoms' (3).
Whereas the uncorrected image shows misclassifications of 90% and 97% (class 2 and 3), the corrected image contains accuracies always higher than 95%. Hence the linear approach is sufficient for this subimage.

Conclusion

The methods of light-fall-off correction in aerial photographs, presented in this paper, seem to be very efficient under certain conditions.
The frequency filtering approach (high-/low-pass) is especially suited for correction of full images, because the light-fall-off shows a nearly symmetrical behaviour. The Fourier-analysis, which must be performed before each filtering, produces periodicities in the representation of the light-fall-off, which corresponds to real light-fall-off.
On the other hand the method of frequency domain filtering is not suited for the correction of subimages, because symmetrical light-fall-off does not exist in most image parts.
The polynomial approximation of light-fall-off is sufficiently applicable to full images as well as to subimages. However the quality of this method depends on the choice of reference points, which must belong to only one class and which must be uniformly distributed over the whole image. With one predominant object class light-fall-off can be supressed very efficient. But with heterogenuous classes best results are only achieved in the reference point-class. The correction in the remaining classes can be unsatisfactory.
For that case a class independent frequency domain filtering must be preferred. For operational performance, the direct frequency domain filter approach should be replaced by a simpler procedure. After an image reduction with an appropriate reduction factor, common moving average technique will yield a low filtered image. The re-enlarged filtered image can be used as light-fall-off estimation. In small subimages a simple linear algorithm can be sufficient for correction of light-fall-off.

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