A POLYNOMIAL APPROACH FOR RADIOMETRIC AERIAL TRIANGULATION

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ABSTRACT:

The introduction of digital cameras within orthophoto production allows two benefits: a considerable reduction in production time for projects, which have an increasing work load, like the Spanish National Program of Aerial Orthophotography (PNOA), lead by the Spanish IGN, and the applying of remote sensing techniques in digital image processing. Even though conventional photogrammetric methodologies for radiometric compensation of aerial images offer solutions that can be fitted to new production strategies, adaptation of this technology isn't feasible yet from a quality potential point of view. The first digital aerial cameras were presented to the Photogrammetric Community at the 2000 ISPRS Congress in Amsterdam. Since then, geometric parameters have been perfectly controlled during calibration and aerial triangulation processes. Contrary to this, and because the radiometic calibration protocols are quite recent, the radiometric processing of images lacks rigorous methodologies. In this paper, an empirical polynomial method for radiometric compensation of digital aerial images is described. This methodology is based on digital aerial triangulation results carried out by means of automated correlation techniques. Radiometic correction functions for each image in a photogrammetric block are then modelled from radiometric samples of tie points. Results obtained by applying this methodology to a Z/I DMC flights within the framework of PNOA's project in Castilla-La Mancha and Andalucía regions, are also presented.

1. INTRODUCTION

The development of photogrammetric systems has historically been focused on purely geometric aspects. It has had an objective orientated towards the improvement of the collection equipment's measurement methods and calculation algorithms to try to obtain the greatest amount of geospatial information in the most precise and automated way possible.

The fact that digital orthophotos – products with geometrical and semantic features – became the most in demand cartographic element, proved the necessity of developing methods for radiometric correction to enable cartographic and visual analysis applications as well.

The introduction of digital cameras opened up the possibility to apply rigorous remote-sensing techniques for the radiometric correction of aerial images and to use them in both visual and quantitative analysis applications.

2. STATE-OF-THE-ART

Radiometry of an aerial image is influenced by atmospheric effects, the absorption of directly transmitted sunlight and the dispersion of indirect light reaching the sensor, as well as the Bidirectional Reflectance Distribution Function (BRDF).

Atmospheric correction methods are based on both physical and empirical methodologies. Physical methods include: ATCOR (Rolf Richter, DLR Oberpfaffenhofen (Germany)), or ACORN (Atmospheric CORection Now, Analytical Imaging and Geophysics, LLC) which use Radiative Transfer Models, like 6s and MODTRAN, the latter of which require knowledge of certain atmospheric parameters that are not directly accessible. The empirical methods use either interactive methodologies by identifying study areas, or statistical methods based on the analysis of histograms or dark objects.

Bi-directional effects have a significant impact on aerial images due to the wide Field of View (FOV) of digital photogrammetric cameras. Likewise, there has been a development of a great number of physical and empirical correction methods. The semi-empirical methods, like Walthall's or Ambral's models, are widespread.

The radiometric correction of an aerial image firstly consists of applying the absolute radiometric calibration parameters obtained in the laboratory. Atmospheric and finally BRDF correction follow. Nevertheless, considering the interactive solutions based on purely visual criteria that are available (both in flight image processing and in ortophoto mosaic generation), few digital camera manufacturers and photogrammetric software vendors have implemented rigorous radiometric correction procedures.

The current PNOA orthophotographic production process starts with the habitual manipulation of the aerial images to obtain, at best, radiometric homogeneity without quantitative criteria. Commercial solutions for orthophotographic production, in contrast, try to solve, in an approximate manner and just in one step, all the effects that apply to image radiometry offering acceptable solutions only for cartographic and agro-environmental applications.

3. POLYNOMIAL RADIOMETRIC AERIAL TRIANGULATION METHOD

3.1 Introduction

Radiometric correction of images – the obtaining of each ground point's reflectance from the Digital Number (DN) of the image's pixel – has been studied in satellite images since the inception of Remote Sensing. The introduction of digital photogrammetric cameras allows a rigorous radiometric correction approach of digital aerial photographs. Achieving this correction would be useful for:

a) Eliminating non-homogeneities and discontinuities in the radiometry of orthophotograph mosaics
b) Obtaining 'real' colour orthophotographs
c) Allowing the use of orthophotographs to obtain biophysical parameters (LAI, FAPAR, etc.)

However, the radiometry's physical formulation of photographs, which can be found in the bibliography, e.g. Slater, 1980, cannot be directly applied to the aerial photographs due to some problems of which the most significant ones are:

a) A lack of knowledge concerning the local atmospheric conditions at the instant of capture.
b) A lack of knowledge concerning the BRDF for each terrain's type present in the photographs.

Therefore, one of the authors of the present study set out, during a visit to the French IGN (Villa, 1988), to use an empirical polynomial method to 'homogenise' pixel radiometry inside each photograph, assigning to each pixel the DN that it would have if centred in the image, and to 'balancing' the radiometry for the different photographs within a block by equalisation of the DN of a given ground point in all the photographs when the given point is present.

3.2 Polynomial mathematical model for the radiometric correction

The proposed empirical method consisted of supposing that between the pixel's radiometric value in an image and its corrected value the following relationship is valid:

$$E_0 = K(x,y) \cdot E \qquad (1)$$

being

E: radiometric value of a pixel as it appears in the image
E_0: corrected radiometric value
K(x, y): correction factor, depending on the position of the pixel in the photograph
x, y: pixel coordinates when they refer to the centre of the image

Additionally there is a supposition that the correction factor could be expressed through a second or higher degree polynomial expression to be determined:

$$k(x,y) = C_0 + C_1x + C_2y + C_3xy + C_4x^2 + C_5y^2 + \ldots \qquad (2)$$

'Radiometric tie points' (RTP) were used to determine the coefficients Ci of the polynomials, i.e. conjugate points from which the comparison of radiometric values in different photographs where they appear, provide equations that permit the calculation of these by imposing the equivalence of the corrected values:

$$E_0 \text{ (image 1)} = E_0 \text{ (image 2)} \qquad (3)$$

The work was done with analogic panchromatic scanned aerial images, and hence the logical working units were photometric (E: illuminance) and the optical 'densities' of the photographic film. In digital aerial images, an empirical model can be directly applied to digital levels by considering geometric and radiometric conversions of the received at sensor radiance during the image acquisition phase.

The present study aims to apply the same formulation with some variations to the current case of multispectral digital photographs coming from digital photogrammetric cameras. An important variant is that in the original study it was supposed that the correction polynomial was the same for all the photographs. The implication being that atmospheric conditions and the BRDF were constant in all the study areas. Whereas, in the present study, each photograph is corrected with an independent polynomial.

Assignment of reflectance physical values of each pixel's corrected DN can be done in a subsequent phase through the use of 'radiometric control points' (RCP), which are ground points from which reflectance has been measured through field radiometry.

Results obtained from tests applied to a set of radiometric tie points confirmed that second degree polynomial in (x,y) yielded good results.

3.3 Mathematical solution of the problem

Under the condition of invariance at the centre of the image, the polynomial expression (1) results in:

$$K(0,0) = 1 \,, \; C_0 = 1 \qquad (4)$$

By resolving the parametric model by ordinary least-squares adjustment (OLS) applied to the selected RTP in the overlapping zone of the images of the block, the adjusted DN for each RGB channel can be obtained as a normal equation system corresponding to a functional model of the indirect parametric observations space.

Taken as initial data the values for a given tie point, the empirical mathematical model (1) can be expressed under the DN equivalency condition of a photogrammetric stereo-model as a linear system of equations in the coefficients of the residual factor expression:

$$DN^o\big|_1 = DN^o\big|_2 \Rightarrow \sum_{i=1}^{5} a_i C_i + \left(DN_2^0 - DN_1^0\right) = 0 \qquad (5)$$

$$C_i \; cte \; \forall \; i$$

being

$$\left.\begin{aligned} a_1 &= x_2 DN_2 - x_1 DN_1 \\ a_2 &= y_2 DN_2 - y_1 DN_1 \\ a_3 &= x_2 y_2 DN_2 - x_1 y_1 DN_1 \\ a_4 &= (x_2)^2 DN_2 - (x_1)^2 DN_1 \\ a_5 &= (y_2)^2 DN_2 - (y_1)^2 DN_1 \end{aligned}\right\}$$

The OLS functional model in matrix form corresponds to:

$$A\underline{C} - \underline{t} = \underline{v} \,/\, A \in M_{npa\ X\ 5} \qquad (6)$$

where

$$A^t = \begin{pmatrix} x_{12}E_{12} - x_{11}E_{11} & \ldots & x_{i2}E_{i2} - x_{i1}E_{i1} & \ldots & x_{npa2}E_{npa2} - x_{npa1}E_{npa1} \\ y_{12}E_{12} - y_{11}E_{11} & \ldots & y_{i2}E_{i2} - y_{i1}E_{i1} & \ldots & y_{npa2}E_{npa2} - y_{npa1}E_{npa1} \\ x_{12}y_{12}E_{12} - x_{11}y_{11}E_{11} & \ldots & x_{i2}y_{i2}E_{i2} - x_{i1}y_{i1}E_{i1} & \ldots & x_{npa2}y_{npa2}E_{npa2} - x_{npa1}y_{npa1}E_{npa1} \\ (x_{12})^2E_{12} - (x_{11})^2E_{11} & \ldots & (x_{i2})^2E_{i2} - (x_{i1})^2E_{i1} & \ldots & (x_{npa2})^2E_{npa2} - (x_{npa1})^2E_{npa1} \\ (y_{12})^2E_{12} - (y_{11})^2E_{11} & \ldots & (y_{i2})^2E_{i2} - (y_{i1})^2E_{i1} & \ldots & (y_{npa2})^2E_{npa2} - (y_{npa1})^2E_{npa1} \end{pmatrix}$$

$$\underline{C} = (C_i) \in M_{5\,x\,1}$$

$$\underline{t} \in M_{npaX1} \,/\, \underline{t} = \begin{pmatrix} DN_{12} - DN_{11} \\ \ldots \\ DN_{i2} - DN_{i1} \\ \ldots \\ DN_{npa2} - DN_{npa1} \end{pmatrix}$$

npa = number of RTP.

In general, when the RGB space colour can be designed from the diagonal hyper-matrix made up of the design matrix for all the channels, adjusted polynomial coefficients in (2) are calculated by solving the related system of normal equations:

$$\hat{C} = (A^t A)^{-1} A^t \; \underline{t} \qquad (7)$$

hence, the estimated DN is obtained by applying formulas (2) and (1) to the set of all points.

3.4 Generalised polynomial method of radiometric aerial triangulation.

Expression (1) is not applicable in cases of non-uniform ground or in cases of different luminosity conditions between consecutive photographies. Consequently, the application of a modified algorithm is necessary to generalise a polynomial method valid for all conditions.

For every image of a given photogrammetric block, the proposed radiometric aerial triangulation method consists in considering, for each independent band, a correction polynomial and applying a non-null correction at the centre of the image (C0≠1). Reference DNr (Digital Reference Levels) can be considered equal to the arithmetic mean of RTP obtained values in each image which provides a BRDF effect-free solution; or values obtained from a reference image, with the possibility of introducing absolute values as RCP to improve radiometric balancing.

$$\frac{DN_r}{DN\ \ (s\ ,l\ )} = C_0 + C_1 s + C_2 l + C_3 s \cdot l + C_4 s^2 + C_5 l^2 \qquad (8)$$

being

s,l: the pixel's coordinates in the digital image system.

Tie points come from automatic digital aerial triangulation measurement, whose reduced positions in the image system are obtained from any commercial aerial triangulation software. Different tie points distribution patterns can be used, the minimal condition being the measure of a point per Von Grüber's zone which guarantees the obtainment of each point's value from each corresponding image; i.e. from each direction, covering the complete photography range. Because local variations produced by perspective and shadow effects would result in changed values which must be removed, the collection of multiple points per area is nonetheless recommended for the obtainment of a redundant system. The DN assigned to each tie point can vary from the corresponding pixel value, to a variable sized window which permits, according to the resolution of the reference images, to clean representative radiometric values from the microscopic noise of shadows.

By applying the previous adjustment to the resulting design matrix, a radiometric empirical correction is applied to obtain an uniform orthophotograph mosaic. A previous absolute radiometric correction is required though to obtain quantitative results.

4. DEVELOPMENT OF THE POLYNOMIAL RADIOMETRIC AERIAL TRIANGULATION SYSTEM

ATRPol is a modular system separating phases for data preparation, system resolution and the parametric application phase. The system works in an automatic and flexible way and it has the hability to be integrated into his orthophotograph production workflow.

The system is currently being developed in a C++ environment (Borland Builder C++ 2006, Microsoft Visual Studio 2006) using the specific graphic libraries for the image treatment (Leadtools Imaging Pro v.10). Figure 1 presents a example of the program interface.

4.1 ATRPol Import Module.

This module has been developed to incorporate radiometric observations of tie and ground control points obtained. These observations have been obtained from aerial photographs and from digital aerial triangulation results. This module works linked to a database constructed from a pre-defined data model of the project to allow the access to the initial information in a more efficient way as well as to register the resultant values for each calculation operation.

4.2 ATRPol Solve Module.

This is a module developed to carry out the “least-squares estimation” of the polynomial radiometric correction coefficients for each aerial photograph and is based on Cholesky 's method for the matrix's inversion of the normal equations system. This module is currently being implemented and requires the consideration of an automatic method for radiometric rough error detection.

4.3 ATRPol Apply Module.

This is a module developed for the application of polynomial correction to each aerial photograph through independent channels. For ATRPol to be an efficient method, all the calculations have to be made over low resolution images, for what a scale factor K regarding the minification level of the analysed image, is introduced within the image cartesian system.

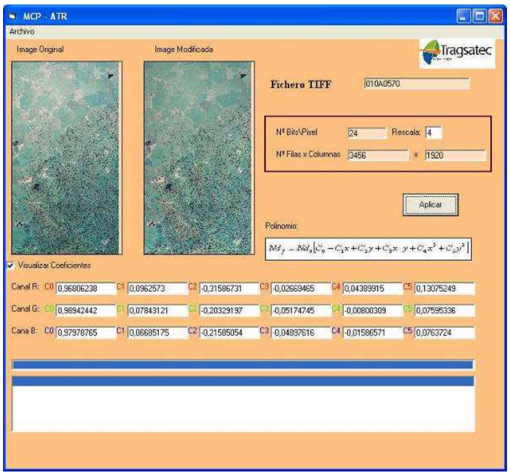

Figure 1.ATRPol application interface. Polynomial application module.

5. PRACTICAL EXPERIMENT.

5.1 Synthetic images.

The possibility of generating synthetic images that simulate different radiometric effects so that correction algorithms could be tested before making the results analysis in a real aerial image case has been a turning point for the development of the system.

A synthetic image consists of an nxn matrix with digital values in a normalised cartesian system. Starting from a matrix with constant values which are equal to a digital average value (flat image error free with a value of 128 using 8-bit) a polynomial P^0 that simulates a known effect is applied to obtain synthetic image affected by the error (I_0 simulated) which then will be used in the application of ATRPol method:

$$I_0(Dn = 128) \times P^0(x, y) = I_0 \ (simulated) \qquad (9)$$

Being the polynomial P^0 as stated by the equation (2).

The opposite problem is to find a correction polynomial P that when applied to simulated images could give us a flat image corrected from digital values which are equal to the reference values.

$$I_0(simulated) \times P(x, y) = I_0(Nd = 128) \qquad (10)$$

If the algorithm correctly works, the image obtained by inversion of the model applying the ATRPol method should be close to the original. Figure 2 shows the correction effect on the synthetic image which simulates a vignetting effect.

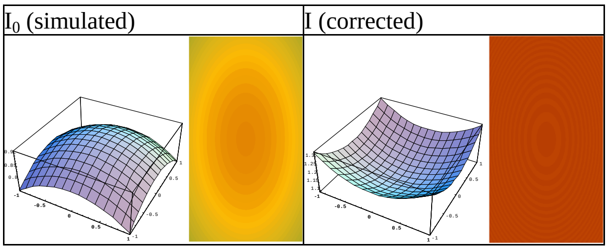

Figure 2. Vignetting's effect simulation and correction through ATRPol

Table 1 shows the polynomials’ coefficients calculated and used to generate these images:

	C_0	C_1	C_2	C_3	C_4	C_5
P^0(x,y)	0.83160	0.00000	0.03776	0.00000	-0.07552	0.02995
P(x,y)	1.09992	0.0000	0.00000	0.00000	0.10939	0.10939

Table1: Values applied for synthetic image simulation calculated by ATRPol

The previous effect does not happen when using digital cameras because the radiometric calibration present eliminates the optical influences of the sensor. Different Hot Spot effects have been simulated to check the correct running of the system (see Figure 3).

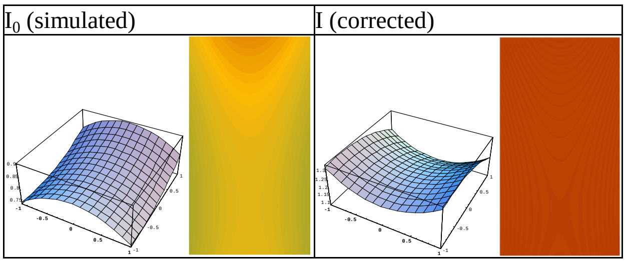

Figure 3. Hot Spot effect simulation and correction through ATRPol

5.2 PNOA images

ATRPol system is now being implemented using images from flights using a Z/I DMC camera, in accordance with the PNOA project.

Two testing areas are considered: one homogenous zone which is located in Castilla-La-Mancha region (2006 PNOA flight, GSD: 0.45m and overlappings 60%-40%) and characterised by flat terrain, tree-free and a big urban agglomeration, and a woodland area located in the region of Andalucia ((2009 PNOA flight, GSD: 0.45m and overlappings 60%-25%) and described by a mountain terrain, a small settlement and a very evident Hot

Spot effect. Both areas have been overflown on sequential dates and under similar luminance conditions. Images have been LUT processed from 12-bit to obtain 8-bit ones and Pansharpened.

For Castilla-La-Mancha area the method has been applied using as reference the RTP average digital value within a window size of 33x33 and separating urban and rural areas. Results have been very satisfactory for rural areas, where there was a good adjustment both for same flight strips and for different ones (fig. 4). In contrast, for urban areas (fig. 5) although correction level is good, small differences between flight strips could not be overcomed.

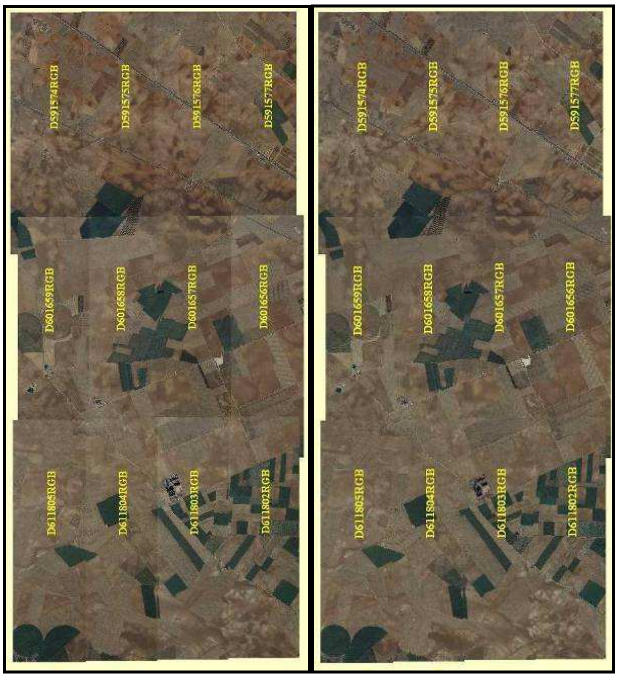

Figure 4. Example of adjustment for rural zone in Castilla-La Mancha. Original photographs (left) vs adjusted photographs

For the Andalucía area, the behaviour of the adjustment on the averaged RTP radiometric values, established as a reference, are similar (Figure 6), even having marked differences of up to 60% in RTP digital levels between flight strips (Figure 7). The obtained adjusted polynomial for each photograph and radiometric channel responds approximately to a systematic Hot Spot correction (Figure 8) and is more evident and centred in flight strip 11.

If we analyse visually the results from the RTP adjustment (Fig. 7), we can notice how the algorithm tends to homogenise the radiometric values of the images without interfering with local contrast. Furthermore, it is necessary to apply a further expansion contrast treatment which is more easily applied to the corrected picture than to the original for avoiding saturations. On the other hand, the adjustment does not affect the colour balance either, due to not having introduced radiometric control points. To conclude the study in the current test areas, we are going to analyse the behaviour of the correction method by introducing RCP from reference images over invariants.

Figure 5. Example of adjustment for urban zone in de Castilla-La Mancha. Original photographs (top) vs adjusted photographs

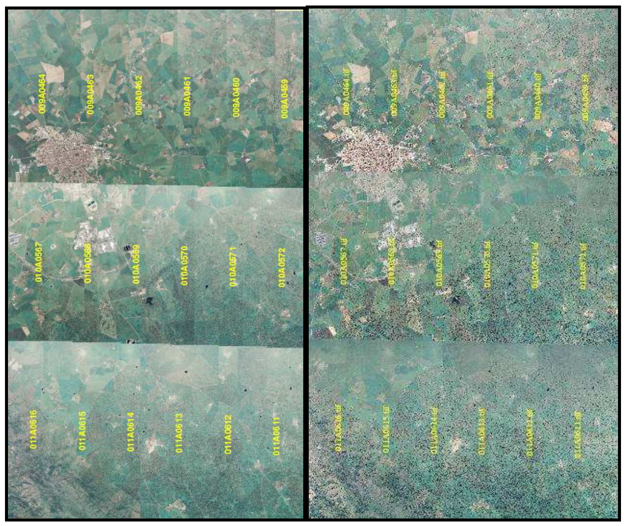

Figure 6. Example of adjustment for the PNOA flight in Andalucia. Original photographs (left) vs adjusted photographs

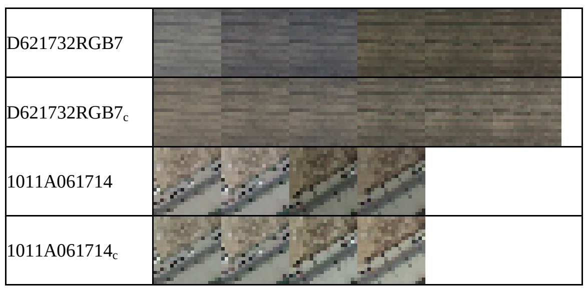

Figure 7. Example of RTP radiometric differences Windows for original and adjusted RTP.