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Relief effects on aerial photos geometric correction

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Abstract

Aerial photos are the best support to detect changes in the landscape over the time, particularly when associated with GIS based analyses. Since all metrics calculated on a landscape (from area coverage by vegetation classes to patches shape and size) are sensible to geometric distortions, the geometric correction of aerial photos is due to allow a realistic multi-temporal study.

In this paper the mostly used methods of rectification were applied to aerial photos of different terrain types, with respect to their roughness (a flat area, a hilly area and a volcanic area), aiming to test residuals in x and y axes, under different conditions of terrain roughness.

Polynomial functions confirmed their power in rectification process only in case of flat areas, with an increase of the error with more rugged terrains; on the contrary, orthorectification assured great results for all terrain types.

Keywords: GIS; Remote sensing; Aerial photos; Polynomial rectification; Orthorectification; DTM; GCPs

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Introduction

Remote Sensing represents a powerful method for researchers to quickly generate thematic cartography, rather than field based sampling methods. In particular, aerial photos are the best support to detect changes in the landscape over the time, since they are available from 1930s (Casson, Delacourt, Baratoux, & Allemand, 2003; Turner, Gardner, & O'Neill, 2001). While terrestrial photos enable the assessment of parts of the landscape (e.g. single species), aerial photos allow a global view at large scales (Innes & Koch, 1998), and represent a quite simple management tool.

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This technology provides the basis for developing landscape composition and structure indices as sensitive measures of large-scale environmental change (Kepner et al., 2000), and is improved by Geographic Information Systems (GIS) that opened many new possibilities in this field of research (Baltsavias, 1996). Before accurate measurements can be made based on aerial photographs, distortion in the photographs must be removed (Powers, Chiarle, & Savage, 1996). Since all metrics calculated on a landscape (from area coverage by vegetation classes to patches shape and size) are sensible to geometric distortions, the geometric correction of aerial photos is due to allow a realistic multi-temporal study. Thus, an orthogonal projection of all points of the image to a reference surface (system) must be applied in order to correct photos of all types of distortion (Novak, 1992).

Various methods of rectification are currently in use, from simple image registration to polynomial functions to rigorous models (orthorectification). Among these, only the orthorectification method takes into account the elevation of the area under study by means of DTMs (digital terrain models). Jensen (1996) reviewed all distortion causes for all types of support either panchromatic photos and satellite imagery. Terrain roughness appeared to be one of the most important, being remotely sensed data affected by the topography on the ground (Hinton, 1996).

Thus, the effects of elevation and slope of an area (strictly spoken, its roughness) could seriously threat the final accuracy of rectification, being its morphology a key factor when deciding which method to use (Paine, 1981).

In order to establish a mathematical relationship between image and corresponding map coordinates, one of the mostly used methods is based on the recognition of GCPs (ground control points) and the application of rectification algorithms. GCPs represent the locational information (x and y in a reference system, Campbell, 1996) of points recognized in the photographs. Only for rigorous models, heights must be part of locational information.

Using appropriate GCPs for both positioning and number (Gibson & Power, 2000; Welch, Jordan, & Ehlers, 1985) it is possible to rectify images in a very simple manner, by ensuring that the resultant RMSE (root mean square error) is under a certain threshold. As for GCPs positioning, they might be dispersed over the area by ensuring a whole cover of the image, without clustering; as for their number, Bernstein (1983) proposed that 16 GCPs represent a reasonable number if each can be located with an accuracy of one third of a pixel. Clearly, the number of GCPs is even a function of the rectification method used.

The polynomial methods considered in this paper are the mostly used in rectification process, since they are easy to apply and implement in commonly used GIS and remote sensing softwares (Novak, 1992; Peroni, Ferri, & Avena, 2000) and they do not require information about the geometry of the imaging sensor (Wiesel, 1985).

Such methods are based on a curve fit, once the GCPs were chosen, respectively of first (Eq. (1)) and second order (Eq. (2)), being the order the higher exponent of the equation.

$$x = a_0 + a_1X + a_2Y \quad y = b_0 + b_1X + b_2Y \tag{1}$$

$$\begin{aligned} x &= a_0 + a_1X + a_2Y + a_3XY + a_4X^2 + a_5Y^2 \\ y &= b_0 + b_1X + b_2Y + b_3XY + b_4X^2 + b_5Y^2 \end{aligned} \tag{2}$$

where (x,y), coordinates of the image to be rectified; (X,Y), coordinates of the reference image or map.

In general terms, the higher the order of the polynomial function, the higher the possibility to correct images for more complex types of distortion. On the other hand, it is unusual to have terms beyond second power (Russ, 2002). In fact, while the higher order polynomials are accurate in the proximity of GCPs they can lead to significant errors, for regions outside the GCPs range (Richards & Jia, 1999).

Instead of polynomial methods, orthorectification takes into account both the elevation of the area, derived from a digital terrain model (DTM), and the camera parameters, namely the focal length and the centre of the camera with respect to the taken photo. We refer to Konecny (1979) and to Novak (1992) for algorithms.

All rectification methods produce a residual in the x and y axes between input and output coordinates; for each GCP, RMSE, e.g. the resultant vector from residuals in x and y axes, is calculated as

$$\mathrm{RMSE} = \sqrt{u^2 + v^2} \tag{3}$$

where u, residual in the x axis; v, residual in the y axis.

Total RMSE is then derived as

$$\text{Total RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} u^2 + v^2} \tag{4}$$

where n, number of GCPs; u, residual in the x axis; v, residual in the y axis.

Testing the model

The aim of this paper is to test residuals in x and y axes, in order to empirically assess potential and limitations of various methods of rectification, under various conditions of terrain roughness.

Study areas were chosen in order to provide a gradient of terrain roughness: Tenuta di Coltano, a flat area near Livorno, Toscana, Italy (centre of the scene: 611414, 4831623, UTM, ED50, 32N); the hills near Siena, Toscana, Italy (centre of the scene: 687731, 4802062, UTM, ED50, 32N), the southeast side of the Etna volcano, Sicilia, Italy (centre of the scene: 498868, 4173096, UTM, ED50, 33N).

DTMs with a cell dimension of 5 m were generated for each area from topographic maps (scale 1:10,000), using elevation contours and points as input datasets within a triangulated irregular network (TIN) model in order to provide a basis for the orthorectification process. Aerial photos with a flight height of 6000 m and a scene of 25 km^2 were acquired with a commercial scanner at 600 dpi. DTMs and derived slope maps were used to characterize each area, by calculating mean elevation and slope, standard deviation, range, e.g. maximum–minimum elevation or slope, maximum local standard deviation, e.g. the maximum standard deviation of a 3 pixel neighbourhood.

For each area the two mostly used methods of rectification were applied: polynomial functions (of first and second order) and orthorectification, by using 20 GCPs and rectifying the photos in UTM(ED50) coordinate system. Resampling was performed by the nearest neighbour method and output pixel dimension was 2 m. Nearest neighbour resampling method simply associates the nearest original pixel brightness value to the corrected image pixel. For each area and rectification method, total RMSE was calculated, and the dispersion cloud of GCPs residuals was plotted in order to verify the relation between terrain roughness and cloud dimensions.

Study findings

DTMs of the chosen areas showed a positive trend with respect to terrain roughness (Fig. 1). Statistics derived from DTM and slope maps of each area showed great differences among areas both in elevation and slope (Table 1). Total RMSE for a flat area (Fig. 2) was found to be very similar for all rectification methods. Considering a more rugged area (a hilly landscape) a dramatic decrease of RMSE values was found passing from simplest polynomial functions to a rigorous model (orthorectification). This phenomenon was evident for a very rugged (volcanic landscape) area.

By considering each rectification method, a linear increase of total RMSE was found, passing from a flat area to more rugged terrains, with a substantial stability of the error in the case of orthorectification. The dispersion cloud of GCPs residuals showed similar dimensions for all rectification methods in a flat area (Fig. 3(a)). The cloud opened up passing to increasingly rugged terrains and more simple rectification functions (Fig. 3(b) and (c)), reaching a maximum value of about 60 m with a polynomial of first order in the volcanic area.

Discussion and significance

Polynomial functions confirmed their power in rectification process only in case of flat areas, but failed in the case of more rugged terrains (Cheng, Yeh, & Tsai, 2000), being therefore inappropriate for cartographic or landscape change detection purposes; on the contrary, orthorectification assured great results for all terrain types and must be used when uncertainty on terrain roughness occurs. Indeed, a stabilisation of total RMSE within a range of 1 m among all terrain types was found from polynomials to orthorectification method. While coarse resolution imagery, e.g. coarse satellite sensors such as Landsat or Spot, contain no significant relief displacement (Konecny, 1979), such displacement must be taken into account when dealing with high resolution supports, such as aerial photos or high resolution satellite sensors such as Quickbird or Ikonos.

The results achieved in this paper must be kept in mind by operators and researchers who aim to analyse landscape patterns for extracting and comparing thematic cartographies. As an example, Rocchini (2004) demonstrated that the change over the time of some classes could be overestimated up to the double of the occupied area.

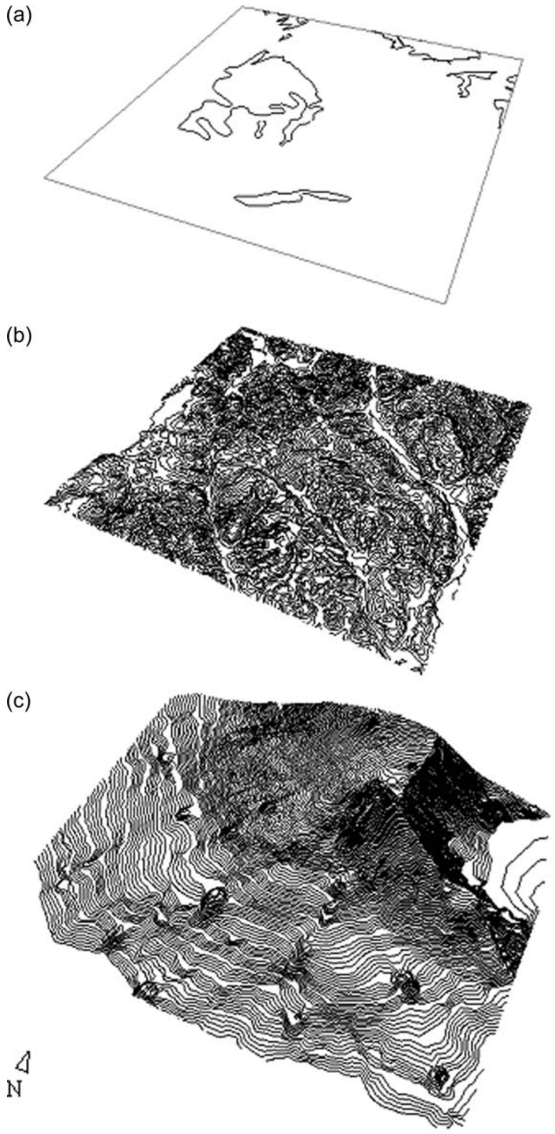


Fig. 1. DTMs of the study areas: (a) Tenuta di Coltano, Livorno, Toscana, Italy; (b) hills near Siena, Toscana, Italy; (c) southeast side of the Etna volcano, Sicilia, Italy.

However, recent spread of user-friendly tools and interfaces to perform simple rectification (see the ESRI internet site: http://arcscripts.esri.com) could give rise to incorrect input information (Georgopoulos & Makris, 1997). Although it may not be necessary to orthorectify images to simply identify the change between two images (Jensen, 1996), we steadily think that no quantitative information must be extracted from

Table 1
Elevation (metres) and slope (degrees) statistics of the study areas

	Livorno flat area	Siena hilly area	Etna volcanic area
Mean elevation	8.2	291.1	1831.5
Elevation std. dev.	2.8	39.6	350.5
Elevation range (max–min)	10	249.3	1492
Max local std. dev. of elevation	0.4	9.6	19.6
Mean slope	0.2	8.7	13.5
Slope std. dev.	0.4	6.5	9.3
Slope range (max–min)	6.4	66.7	78.8
Max local std. dev. of slope	3.2	25.3	30.3

geometrically incorrect photo, until proper tests on geometric accuracy were engaged. Several authors, however, made use of these techniques and speak furthermore about measures as hectares or acres or landscape shape metrics (Rocchini, 2004). This clearly leads to misleading results; without implicit assumptions on remote sensing data acquisition and analysis further discussions on obtained results are simply trivial (Duggin & Robinove, 1990).

Moreover, since it is possible to re-calculate the RMSE of every new GCP and therefore its influence on the total RMSE, several authors suggest, especially when using polynomial functions, to remove those GCPs that lead to a great increase of total RMSE (Gibson & Power, 2000; Jensen, 1996; Richards & Jia, 1999). Although standards on GCP removal are available (Toutin, 2004), removing those GCPs that lead to a great increase of

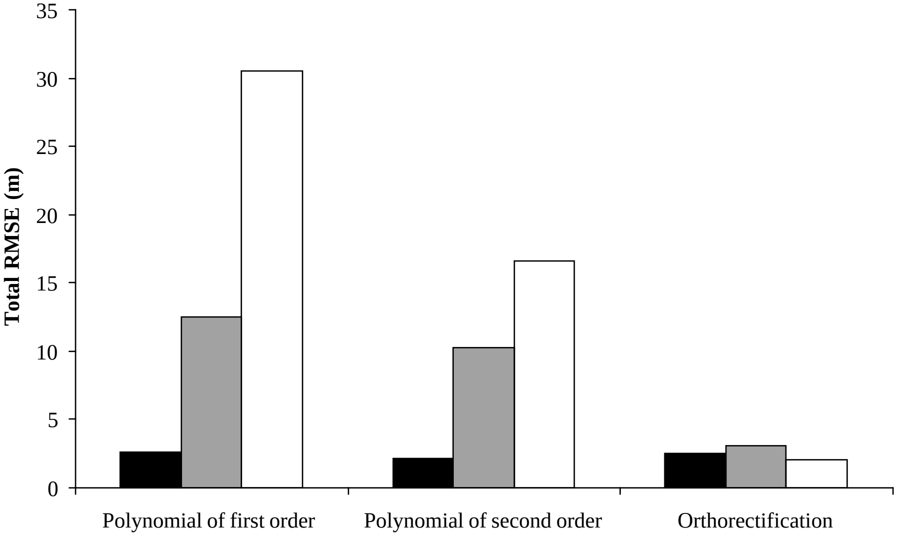


Fig. 2. Total RMSE obtained using polynomials of first and second order and orthorectification for each area. Black columns: Livorno, flat area; grey columns: Siena, hilly area; white columns: Etna, volcanic area.

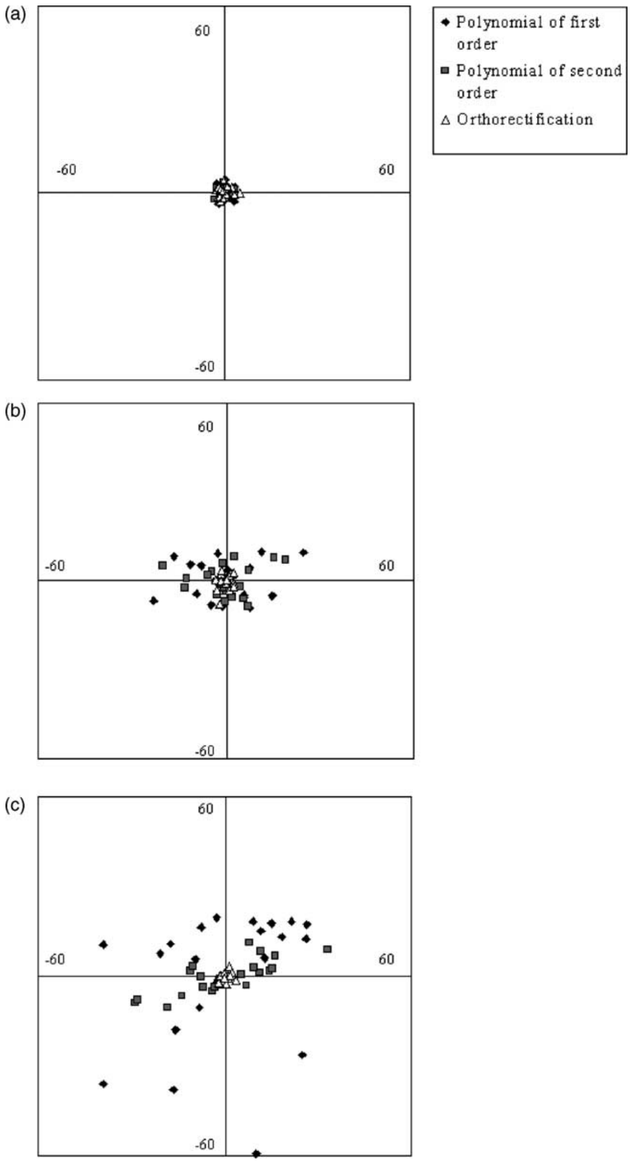
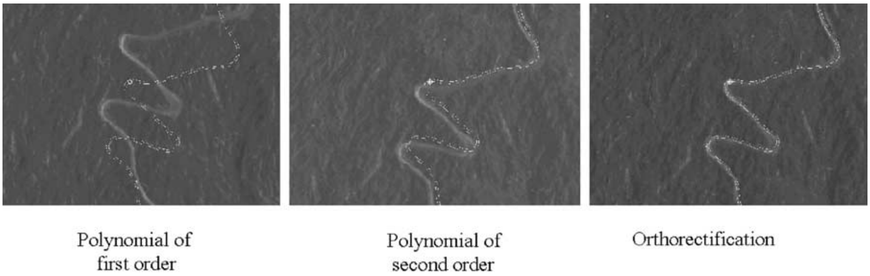


Fig. 3. Dispersion cloud of GCPs residuals (metres) in: (a) Livorno, flat area; (b) Siena, hilly area; (c) Etna, volcanic area.

total RMSE cannot represent a valuable method to guarantee an accurate rectification (Morad, Chalmers, & O'Regan, 1996).

In fact, two fundamental issues must be considered: (I) the error of each GCP often is not connected with positioning errors; (II) the use of few GCPs, although in some cases it



Polynomial of first order

Polynomial of second order

Orthorectification

Fig. 4. Rectification of the Etna (volcanic terrain) photo in the GCP 11 neighbourhood.

could maintain a low RMSE, could be not sufficient to guarantee an accurate rectification (Richards & Jia, 1999).

As for point (I), operator tends often to eliminate those GCPs that affect total RMSE, by adducing 'false' positioning errors as justification. The increase of total RMSE often is not due to positioning errors of new GCPs. As an example, the error of 60 m reached by GCP 11 of Etna photo could suggest a positioning error, but this point has no positioning errors as shown in Fig. 4. Indeed, the RMSE of this point abruptly decreases from 60 to 14 to 1 m by increasing the complexity of the applied function.

Concerning with point (II), although the use of few GCPs can in some cases allow a low RMSE, as the number of points increases the RMSE should stabilise (Fig. 5, as an example, this was achieved by randomly selecting a progressive number of GCPs and recalculating RMSE step by step). Reaching a lower value of RMSE is almost impossible, because RMSE is simply sensible to the applied function. Therefore, in some cases, a low RMSE is not an index of high accuracy but simply of the application of too few GCPs to reach error stabilisation. For example, in this case (Fig. 5) using eight GCPs could give rise to misleading information about the accuracy reached by polynomial functions.

As stated by Boyd, Foody, and Ripple (2002), there is a pressing need for accurate information on landscape change since this is one of the most notable agents of regional-to-global-scale environmental change. In geographical and landscape analysis, strictly connected with GIS information extraction (Mertens & Lambin, 1997), there is a close connection between thematic and geometric component of data (Buiten & van Putten, 1997).

In the era of digital images, where digital images are processed by users whose expertise is in other fields (Krupnik, 2003), we are claiming in this paper that careful tests should be engaged both before and after rectification processes. Before rectifying an image, operator must check for no overall terrain roughness, and after image rectification must no rely only to total RMSE (Buiten & van Putten, 1997), since several other error types such as 'false' positioning errors, too few GCPs to reach error stabilisation, inaccurate chosen functions could be detected by performing more accurate analyses.

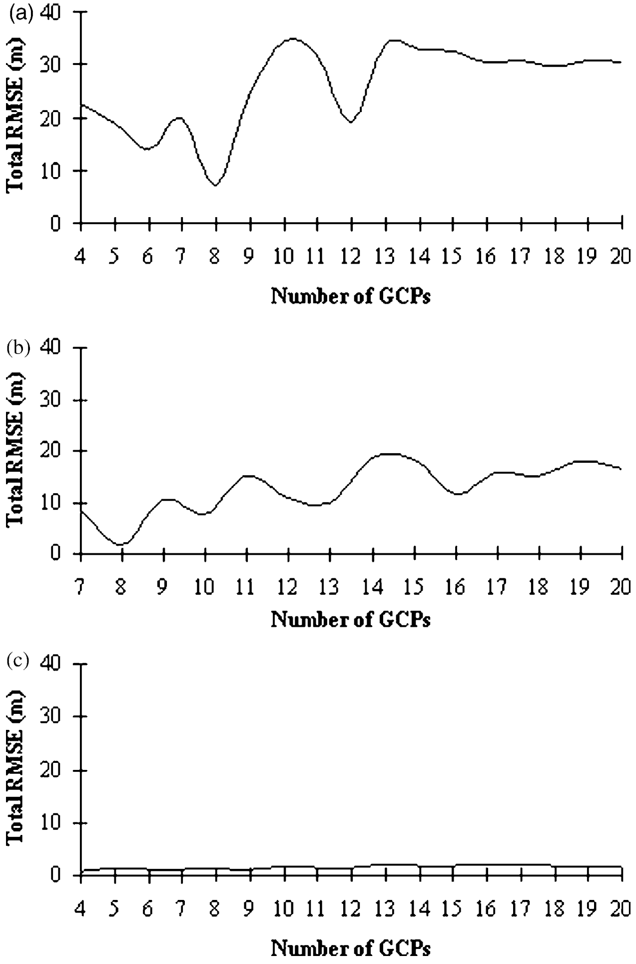


Fig. 5. RMSE variation with respect to the number of GCPs in the Etna area. These trends were obtained by randomly selecting GCPs in order to assess the effect of GCPs number on RMSE. (a) Polynomial of first order; (b) polynomial of second order; (c) orthorectification.

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