MATHEMATICAL RECTIFICATION OF AERIAL PHOTOGRAPHS FOR CADASTRAL MAPPING IN BOLIVIA

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ABSTRACT

An effort has been made, to develop a cost-effective technique for CLAS, in order to generate large-scale maps for cadastral applications using medium resolution scanned aerial photographs, a low-cost scanner, mirror stereoscopes, GIS software and GPS survey systems. Considering the Bolivian half-meter RMSE accuracy requirements for cadastral maps and the flatness of the terrain, we selected the ILWIS implemented projective transformation method as a good solution for the generation of such maps. The projective transformation method, recommended for scanned, near-vertical aerial photographs, requires a minimum of four control points in order to solve the equation system, but at least one extra point must be used in order to evaluate the internal rectification accuracy. To the present, an urban area of about 10 km^2 was covered including 8142 cadastral parcels and approximately the same amount of building blocks. Rural areas are still undergoing census work so we are waiting for these results in order to follow with the digitizing process. The suitability of the accuracy of such data acquisition procedure, which eliminates the conventional 3D photogrammetric process for mapping production, has been discussed. Finally, the study highlights a technique that also helps to integrate aerial photography as a cartographic base to Geographic Information Systems to be used in small towns of similar characteristics.

1 INTRODUCTION

1.1 The playing field

The Centro de Levantamientos Aeroespaciales y Aplicaciones SIG para el Desarrollo Sostenible de los Recursos Naturales, CLAS, is a joint effort of three higher education institutions: International Institute for Aerospace Surveys and Earth Sciences, ITC, from Enschede - The Netherlands, Universidad Mayor de San Simón, UMSS, from Cochabamba - Bolivia, and the International Institute for Infrastructural, Hydraulic and Environmental Engineering, IHE, from Delft - The Netherlands.

As part of its work as disseminator of new methodologies in spatial information production, CLAS is currently involved in the creation of a spatial information system called SISPLADE (System for Planning and Development) to be set up in Colcapirhua, a small town located at six kilometers from Cochabamba, Bolivia.

In this context, one of the most important tasks for CLAS was to perform a 1:1000 scale cadastral survey of both urban and rural zones of Colcapirhua, over an area of 33 km^2 approximately, with a gentle slope going downwards from north to south and a building area clustered around the Blanco Galindo Avenue, which is crossing Colcapirhua form east to west, connecting it with Cochabamba and Quillacollo, the other city of the Cochabamba Valle Central region.

Figure 1. Colcapirhua

1.2 The problem and its solutions

Over the past decades, new tools and their associated methodologies have been emerging in order to prepare cadastral maps at large scales, also new requirements have arisen from the application of GIS technology in the implementation of Planning and Development Support Systems, but in developing countries, funding is usually the main concern.

Since we were facing the usual problem of doing our best with a low budget, we tried to make optimal use of CLAS "in-house" resources, which in our case were a number of PCs and mirror stereoscopes, a ScanJet 4c from Hewlett Packard, the ILWIS version 2.23 software by ITC & PCI for image processing, and two single frequency GPS Surveying System 300 from Leica for ground control survey.

Taking in to account these available resources, the accuracy requirements for both urban and rural cadastral maps in Bolivia (0.50 m and 1.00 m RMSE each), and also the terrain's flatness (although gently sloped), we considered the mathematical rectification or digital rectification approach, as a cost-effective technique for generating large scale maps for cadastral applications using scanned aerial photographs and standard software packages (Govil, 1999).

2 METHODOLOGY

To cover 33 km^2 with a cadastral survey in order to generate 1:1000 scale series of maps over this plane but sloped municipality, we explored the idea of not using a conventional 3D photogrammetric survey. Then, the main concern was to avoid, as much as possible, the relief distortions affecting aerial photographs to be used as background for later on-screen digitizing.

Consequently, we kept the relief problem in mind when we were performing each step of the data acquisition chain. So we did, and performed the processing steps that follow.

2.1 The flight

Knowing the radial pattern of relief distortion in an aerial photograph, the first idea was to use in the process only the central part of each photograph. So, both sidelap and overlap were decided to be 60 %. The advantages of such arrangement were two:

- there were two different and independent sets of aerial photographs, one to be used for Ground Control Point (GCP) surveying and the second one to be used for photointerpretation in the office, and
- any point in the area was imaged from at least nine different aerial photographs, minimizing in this way problems with building and tree obstructions and helping the interpretation during on-screen digitizing.

In order to decide the photo scale, we assumed that the RMSE required should be represented by three pixels (Welch, 1996). This assumption yielded a pixel ground size of 16.6 cm. Now, since the best scanning resolution of our hardware was 600 dots per inch (dpi) or 42 µm pixel size, the final photo scale was set to 1:4000.

The last consideration was to have a flight with the least possible attitude deviation from vertical, in order to minimize the distortions due to the non-parallelism of image and reference planes. Therefore, the angular deviation from the vertical for the camera axis was set to be less than 5 degrees.

With all these requirements, the Servicio Nacional de Aerofotogrametría, SNA, a Bolivian Air Force branch, made the flight, producing almost 300 aerial photographs arranged in 15 lines. The aerial photographs were recorded from an altitude of approximately 600 m over the mean ground elevation, with a focal length of 152 mm using a RMK TOP 15 Zeiss camera.

2.2 Scanning photographs

To assure both image and geometric quality of the digital data, we tried some basic tests with our scanner. In the first test, considering the fact that the photographs were going to be used for on-screen digitizing and for GCP marking in the field, we selected the best gamma factor to be used for scanning aerial photographs, based in visual evaluation of the screen and using a trial and error approach.

The second test was to scan a piece of an old grid layer used for printing maps in the conventional way (color separation). We assumed this grid to be as a stable grid produced with a superior geometry quality than that of our scanning hardware. As a result of this test we confirmed that the geometry was good enough for our needs and that any geometric error would be corrected when the mathematical rectification process would be run.

Once we had the paper prints of each photograph we chose those that were inside the study area. A total of 244 photographs were selected.

The central portion of each photograph was marked with wax pencil in such a way that the scanned portion of a photograph had an overlap with the scanned portions of the four nearest photographs. Then, we scanned a square, with each side being a little bit more than 40 % of the original side of each photograph.

Photographs were scanned as BMP raster images at a pixel resolution of 42 µm (600 dpi), each pixel had a gray value ranging from white to black encoded as an 8-bit byte with 0 representing black and 255 representing white. At the end, we had 244 files of 7.5 MB each that later were imported to ILWIS.

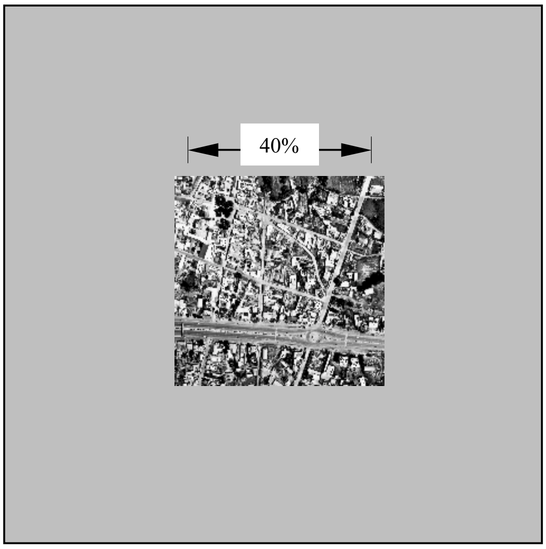

Figure 2. Scanning Aerial Photographs

2.3 Control location and measurement

The distribution of Ground Control Points (GCPs) was done in such a way that they could be used in as many photographs as possible. The problem was that we found that there was a misalignment between even and odd flight lines. This changed our original configuration and we finished with the arrangement shown in Figure 3.

As can be noticed, the photographs in even lines had a GCP in each corner, and every fifth photograph along these lines had an extra GCP in order to obtain an optimum solution. Once the photographs with a total of five GCPs were rectified, they were used to get extra control points, the so called Photo Control Points (FCPs).

These FCPs were used in those photographs with only four GCPs in order to have more than the minimum number of points needed to compute the rectification parameters. Finally, in the case of odd lines, the procedure was to use two GCPs and four FCPs to make such computations.

This way of placing the control reduced the number of points to be measured with the Leica GPS at field.

These measurements were carried out using a single frequency system, with a 20 minutes occupation time in each point and referencing all of them to a base station located at the roof of the Colcapirhua municipality building. The maximum rover-base distance was 4.5 km. Therefore, we expected a subdecimeter accuracy. To assist the point selection and marking directly in the digital photograph in the field, a laptop with the digital data and the ILWIS package was used in conjunction with the GPS system. An average of 10 points per day could be measured under normal working conditions.

Once the GPS data were processed, the coordinate values for each point were introduced to the ILWIS software and after a quality check, those photographs with five GCPs were ready to be used.

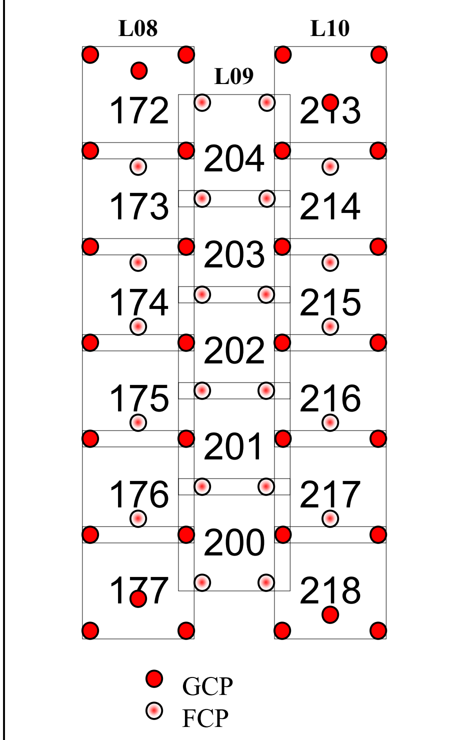

Figure 3. Control distribution

The FCP determination was carried out manually on the screen by an operator helped by printed photographs and a mirror stereoscope. The procedure was to flip on the screen the enlarged part of an already rectified photograph together with the enlarged part, of the same area, on the photograph that was going to be rectified. Then, this area was observed under the stereoscope in order to select and check the FCP to be marked. In this way, an average of 10 photographs could easily be rectified by one operator in one day.

2.4 Selecting the rectification method

Aerial photographs must be geometrically corrected before they can be used in an on-screen digitizing. The process of correcting and removing these displacements can be divided in two steps: to correct the systematic distortions (i.e., those produced by lens distortion, earth curvature, refraction and scanning), and rectification, to remove the effects of tilt and establish scale.

Since the photographs were taken with a photogrammetric camera at a relatively low altitude, and the scanning pixel size was 42 µm without noticeable geometric distortions, we can consider the previously mentioned systematic distortions negligible.

As part of the digital rectification process, the mathematical relationships between the map coordinate system and the scanned aerial photograph must be determined. These relationships can be modeled using one of several algorithms, each of them having advantages and disadvantages.

What follows is a short description of some of them, including an analysis to select the one that can be achievable and that can fulfill our needs of accuracy and costs.

2.4.1 Polynomial-based algorithms. This is perhaps the method most commonly used. It is based on the determination of polynomial coefficients for two transformation equations using a least squares adjustment over a number of control points with coordinates in a ground reference system, like UTM, and in an image reference system, like row and column. The polynomial transformation can be written as:

$$r = \sum_{i=0}^{n}\sum_{j=0}^{i} a_k x^{i-j} y^i \quad \text{, and} \quad c = \sum_{i=0}^{n}\sum_{j=0}^{i} b_k x^{i-j} y^i \tag{1}$$

where:

$$k = \frac{i(i+1)}{2} + j$$

(***x,y***) = control point coordinates in the ground reference system
(***r,c***) = control point coordinates in the image reference system
a_k, b_k = equation coefficients
n = the order of the polynomial

This method has two special cases, the affine and conformal 2D transformations. Since it is the method most commonly implemented, it is available in practically any image processing software. Although it is easy to understand and requires few control points, it does not take in account the geometry of aerial photographs, and when the ***n*** value is more than one it is not a planar transformation anymore.

2.4.2 Projective transformation. In the most general case, a 2D Helmert transformation defines a relationship between points in two parallel planes given by a parallel projection, This means that all projecting lines going from one plane to the other are parallel. If the two planes are not parallel, then the projection can be defined as a 2D affine transformation.

Finally, if the two planes are not parallel, and even more, the projecting lines are not parallel, but have one common point (called projection center), then we have a perspective or projective transformation that can be formulated by (ITC, 1998):

$$r = \frac{ax + by + c}{gx + hy + 1} \quad \text{, and} \quad c = \frac{dx + ey + f}{gx + hy + 1} \tag{2}$$

where:
(***x,y***) = control point coordinates in the ground reference system
(***r,c***) = control point coordinates in the image reference system
a,b,c,d,e,f,g,h = equation coefficients

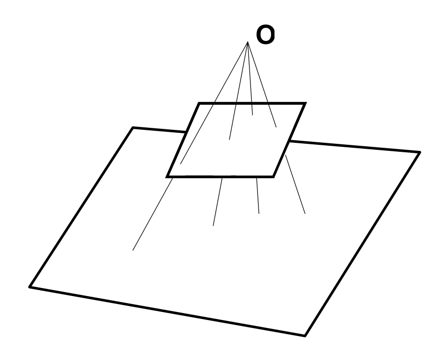

Figure 4. Projective transformation

It is clear that when the ***g*** and ***h*** coefficients are zero, this transformation may become an affine or conformal 2D transformation, depending on the relationships between the remaining coefficients.

Its major advantage is to be a plane-to-plane transformation that uses the central perspective geometry of a photograph in its formulation. In addition, the control requirements are not so different from the first order polynomial approaches.

2.4.3 Piecewise transformation. The piecewise transformation works in two major steps. It first computes the Delaunay tessellation from a set of control points, and then it establishes the image - ground transformation parameters (Ochis, 1998). In other words, it rectifies photographs based in triangle patches, assuming each of them as the ground reference plane for the transformation.

Since the software implementation of this method was not available at CLAS, we did not do much analysis on it. Nevertheless, we can guess about two major disadvantages: it needs more control points in order to layout a good triangulation construction and it does not deal with the points falling outside the region of the triangulation

3 EXPERIMENTS

It is well known that while conformal polynomial method needs at least two control points, and affine polynomial approach will require a minimum of three well-distributed control points, and the more complex projective approach will need at least four control points per photograph.

As a conclusion, the number of points for these three approaches are more or less similar, for which costs will not increase dramatically if we apply one method or the other. In order to select one, we applied these methods over several photographs using the same control points, in order to compare the sigma value reported in each adjustment. The results are shown in Table 5.

Aerial Photo ID	Control type	σ value (in pixels) for each method		
		Conformal	Affine	Projective
L15-312	5GCP	6.959	7.330	1.071
L14-293	5GCP	15.757	14.772	1.069
L14-299	5GCP	12.991	15.832	0.727
L12-258	7GCP	18.976	20.939	0.506
L12-261	5GCP	12.626	14.491	1.179
L10-210	7GCP	18.867	20.205	0.975
L10-219	6GCP	20.338	22.649	0.972
L08-170	5GCP	16.444	18.599	0.340
L08-178	5GCP	9.810	12.013	0.271
L02-026	5GCP	7.941	15.579	1.195

Table 5. Sigma value (in pixels) for each rectification method in ten aerial photographs

It must be noted that FCPs would be affected, in some way, by the method used for the rectification of the photograph from which we are reading its coordinates. Therefore, the comparison was done only for photographs that do not use them. The results speak for themselves. Based on it, the projective approach was considered as the most suitable for the rectification of all project photographs.

Finally, it has to be noted that a maximum sigma value of 1.25 was accepted as the result of the rectification of each photograph. Since each pixel represents one square of about 16.6 cm, the maximum sigma represents 0.21 meters in the terrain. If the value was bigger than this limit, extra GCPs were measured using GPS.

4 RESULTS AND CONCLUSIONS

As soon as the photographs were rectified, they were used as the background over which the parcel limits and buildings were digitized. The same equipment used in order to support operator's visualization of each GCP was used in "on screen" digitizing or monoplotting. In this way, distortions due to elevations of building were taken in account when parcels and edification boundaries were mapped.

In addition, information from cadastral census with a sketch of each cadastral parcel was available during digitizing. Spatial data was organized in layers one for cadastral parcels, one for each building floor, and one for street center lines.

At present, the whole urban area is already covered (about 15 km^2) with a total of 8142 cadastral parcels and approximately the same amount of building blocks. Rural areas are still undergoing census work so we are waiting for these results in order to follow with the digitizing process.

The main conclusion is that the projective transformation can achieve over flat areas the accuracy requirements imposed by Bolivian regulations. The main benefit of it is that the procedure does not need costly photogrammetric equipment, with the exception of mirror stereoscopes, which can easily be used by people with a low training level. The only costly equipment is the GPS surveying receivers, but they can be replaced with total stations, or aerialtriangulation procedures.

In other words, it gives the opportunity for small towns of similar characteristics to have the geoinformation they need with a basic trained team and at an affordable cost.

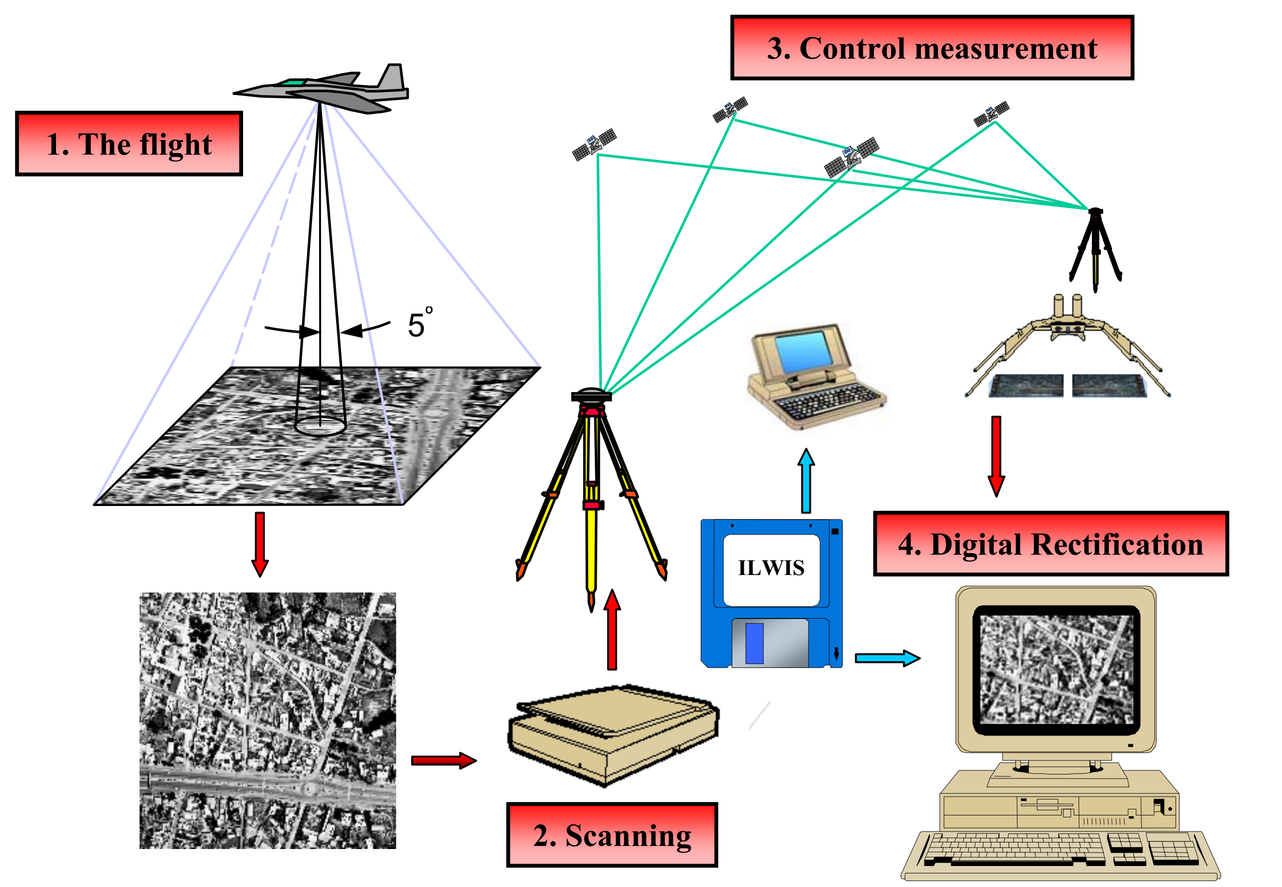

Figure 6. Data Acquisition Chain

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