DIRECT GEOREFERENCING OF DIGITAL CAMERA IMAGES FOR STEREO PLOTTING

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ABSTRACT

In the years of 2004 to 2006, the Portuguese authority for forestry, the *Direcção Geral dos Recursos Florestais* (DGRF) ordered a digital photo flight over the whole country. The images, acquired with a Vexcel UltraCamD digital camera, have a GSD of about 50 cm and GPS/IMU data from an IGI AeroControl IId system were also available for most of the flown strips. Although the first objective of the images was to produce orthophotos to be used in the updating of the national forest inventory, several national institutions are using parts of the digital coverage for other products. In the *Instituto Geográfico do Exército* (IGeoE), the Geographic Institute of the Portuguese Army, a block of 142 of the existing images was analysed in order to conclude about its suitability for the actualization of the military cartography in the scale 1:25000. This paper describes the analysis made to the block from the point of view of a producing institution, whose concerns were mainly whether the geometric accuracy and radiometric resolution of such images fulfil the requirements for military mapping and whether the provided GPS/IMU data were accurate enough for dispensing aerotriangulation and ground control points.

1. INTRODUCTION

Images from digital aerial cameras are beginning to get common in Portugal. Although national flight companies are still equipped with analogue cameras, foreign companies with digital ones are winning the run for greater projects. From November 2004 till June 2006, the whole country has been covered with digital images ordered by the national authority for forestry DGRF (*Direcção Geral dos Recursos Florestais*). Orthophotos have been produced from these images to be used in the updating of the national forest inventory. The images were taken with a digital aerial camera Vexcel UltraCamD from a flying height of about 5600 m and have a GSD (ground sample distance) of ca. 50 cm which corresponds to a scale of approximately 1:56 000. An IGI AeroControl IId system was used during the several flights, so that GPS/IMU data is available for most of the images taken (Patrício, 2006). As the general visual quality of the coverage was considered to be very good, in spite of the rather small scale, other national institutions are taking advantage of the existing digital photos for other purposes. The Geographic Institute of the Portuguese Army IGeoE (*Instituto Geográfico do Exército*) is responsible for several mapping series of the country, including the military map at scale 1:25000. Such a complete up to date coverage of the whole country done in a relative short period of time seemed most interesting for map actualization. Therefore, a sub-block acquired in November 2004 over a rectangular area with 32 km x 20 km located in the central region of the country was analysed in terms of image quality, geometric accuracy and of direct georeferencing for mapping by means of stereo plotting. For this study cooperation between IGeoE and the Faculty of Sciences of the Lisbon University was established. The main question to be answered at the end of the analyses was whether partial blocks of this digital coverage can be used for mapping in scale 1:25000 and whether it can be taken advantage from the GPS/IMU data for direct georeferencing, without having to measure new ground control points.

2. TEST BLOCK CONFIGURATION

The test block STAM consisted of 6 strips in E-W orientation with a total of 142 colour photos with a pixel dimension of 9 µm and a format of 7500 x 11500 pixel. Right from the beginning it was obvious that the block wasn't homogeneous, one of the strips (on the South) having been taken at a different date. In addition there was a gap of 2 photos in the third strip (from the North) causing certain instability in the block. Except for the values of synthetic focal length, and principal point coordinates for two different cameras (two different inner orientations of the same camera), complete calibration reports were not available.

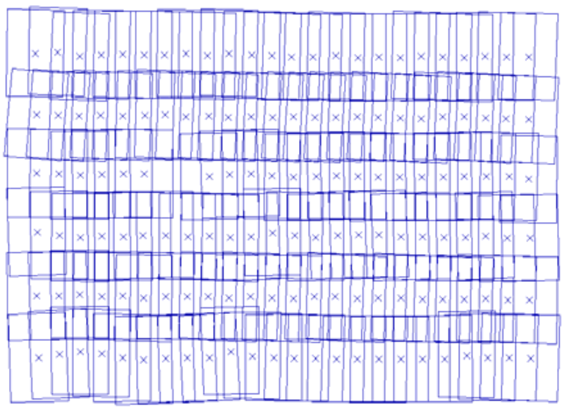

Figure 1 – Test block STAM

The program ISAT (Intergraph) was used to obtain the set of photo coordinates of homologous points in the whole block used in the study. The analyses were made by using both ISAT and the Hanover Software Package BLUH. While map coordinates were used in all ISAT experiments, for BLUH operations these have been transformed to a tangential

coordinate system, since this corresponds to the rigorous photogrammetric object coordinate system. For the final proof, stereo models were set and check points have been stereoscopically measured by means of the program ISSD (Intergraph) that would also be used for the complete stereo plotting.
Two sets of known ground points were alternately used as control and check points. The first set consisted of 88 ground triangulation marks and the second one consisted of 77 new determined ground points by means of GPS positioning (Fig.2).

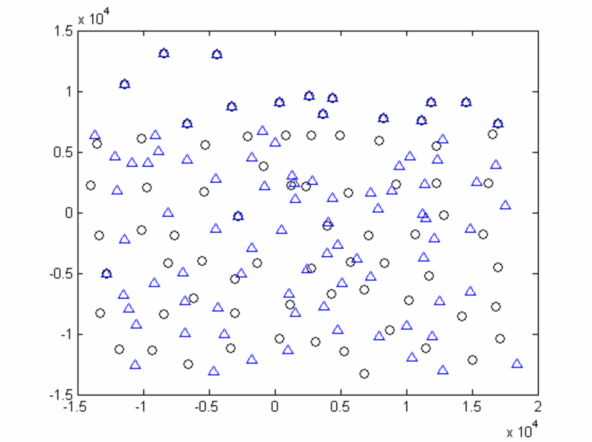

Figure 2 - Ground triangulation marks (triangles) and GPS determined ground points (circles)

The local geoide undulation in relation to the WGS84 ellipsoid was also determined by GPS positioning in 12 well distributed ground triangulation marks.
GPS/IMU flight data was available for every photo.

3. FIRST APPROACH

Assuming the established workflow based on analogue photos as a reference, the new block was at first analysed from the point of view of the map producing customer.
The scepticism about the unusual ratio of 1:2,2 between photo and map scale (for analogue photo flights IGeoE used to require a ratio near 1:1) vanished as experienced technicians observed in detail the individual images. The radiometric quality and detail definition of the digital images have shown to be adequate for mapping in the pretended scale.
On the other side, in spite of the scale reduction, the small format of the digital images, principally along the strips, requires the stereo plotting of about 58 % more models for the same rectangular area.
As for the relative unfavourable base to height ratio of 1: 3,8 (instead of 1:1,6) it is a question that can't be neglected in stereo plotting while affecting the Z accuracy. Proposed solutions to this limitation of the camera (Leberl et Gruber, 2005) include a greater forward overlap (80%) and the creation of DEMs numerically with non-adjacent images, which overlap is reduced to a thin stripe of 20% of the photo length in flight direction. Unless it is possible to carry out a DEM supported stereo plotting, it doesn't seem efficient to stereo plot such a large amount of thin stripes to get the same Z accuracy as if one had a bigger image format.
The gap in the third strip corresponds to an area of 3780 m x 2318 m that can't be stereo plotted using this flight.

The next step after analysing the quality and characteristics of the coverage consisted in setting the models in the photogrammetric workstation and see how it looks like at the control points.
The delivered GPS/IMU data applied as exterior orientation parameters showed to produce intolerable y-parallaxes in the zoomed models, making any control point measurement impossible. This situation occurred in the whole block, but the amount of y-parallax was smaller in the last strip that belonged to the second flight. The camera calibration information included photo coordinates of the principal point of auto collimation (PPA) of (- 0.462 mm , -0.097 mm) for the camera of the upper strips and (0,0) for the camera of the southern one (Gaspar, 2007). The role of such values in a synthetic image was not very clear.
As the stereo plotting was not possible and there was no information available about the GPS/IMU calibration, it was decided to search for the reasons by analysing following items:

- block geometry without GPS/IMU data
- digital image geometry
- GPS/IMU data
- camera calibration data

A set of photo coordinates was automatically acquired by image matching and the photo coordinates for both sets of known ground points have been manually measured. Although well defined in the terrain and easier to locate on digital than on analogue photos, the ground triangulation marks were not very easy to measure due to the poor contrast with the immediate neighbourhood (Gaspar,2007). This fact can compromise the precision of the ground controlled AT.

4. REFERENCE BLOCK ADJUSTMENT

4.1 Ground control supported AT

A classical aerotriangulation supported by ground control points was calculated in order to test the block geometry and to acquire reference exterior orientations. Using the program BLUH, additional parameters referring to affinity and radial symmetric distortion were considered, as well as special parameters for the UltraCamD. In ISAT this last option was not available.
Table 1 resumes the resulting RMS for the ground control points. Table 2 is showing the differences at independent check points.

	σo (μm)	RMS X (m)	RMS Y (m)	RMS Z (m)
ISAT	3.9	0.127	0.105	0.034
BLUH	4.6	0.358	0.307	0.615

Table 1 - RMS in control points after AT

	Nº of check points	SX (m)	SY (m)	SZ (m)
ISAT	75	0.987	0.451	1.044
BLUH	75	0.507	0.463	0.903

Table 2 – Discrepancies at check points after AT

The same sets of photo coordinates and control points were used in both programs. Although the results from ISAT in Table 1 seem to be better, the discrepancies at the same set of independent check points (table 2) show that the indicators from BLUH are more realistic. This corresponds to an accuracy at check points of ca. ± 1 pixel for X and Y and 0.15‰ of flying height above ground for Z. These values are not very different from those achieved in similar conditions by other authors (Baz et al., 2006) although far from the values of 0.05 ‰ and better achievable by UltraCamD with greater photo scales and overlaps (Gruber et Ladstädter, 2006). Assuming the value of sigma naught (4.6µm), as the precision of one photo coordinate measurement, the theoretical precisions for the present flight according to Kraus (1997) are SX = 0.52 m , SY = 0.74 m and SZ = 1.36m (σ_{px} = ± 6.5 µm). The present results confirmed these precision values for this coverage.

4.2 Digital image geometry

The digital colour images of UltraCamD are the result of an elaborated process transforming nine partial panchromatic images, obtained from four parallel mounted cameras (Fig. 3), and three colour bands, obtained from three independent cameras, in one central perspective synthetic image with a focal length of approximately 100 mm.

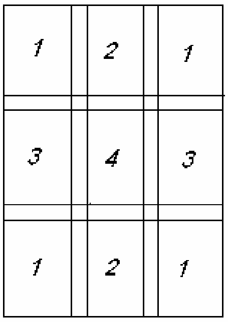

Figure 3 – Panchromatic mosaic sketch. 1 to 4: number of the source camera of the partial image.

In some images of this flight, especially near the coast and over water, seam lines of partial images are detectable (Fig.4). Such an effect is irrelevant for stereo plotting. For orthophotos of regions which include water surfaces, such as lakes, it can be disturbing requiring more post-processing.
The geometry of the image is defined by the final panchromatic mosaic, the colour being obtained by pan sharpening (see Gruber et Kruck, 2006).
It was expected that such a synthetic image would be an absolutely plane surface without any image systematic errors. The analysis of the influence of self-calibration parameters in the photo coordinates, including the special UltraCamD additional parameters, by means of BLUH revealed some systematic errors instead (Fig. 5). A similar configuration has been found by other authors (see Jacobsen, 2007). In some image regions the systematic errors seem to be greater than 1 pixel. If the systematic image errors can't be respected in the photogrammetric workstations, digital elevation models will be affected by model deformation (Jacobsen, 2007). So will be also the object coordinates resulting from stereo plotting.

Figure 4 – Digital photo including water. Seam lines of the nine partial images are visible as edges.

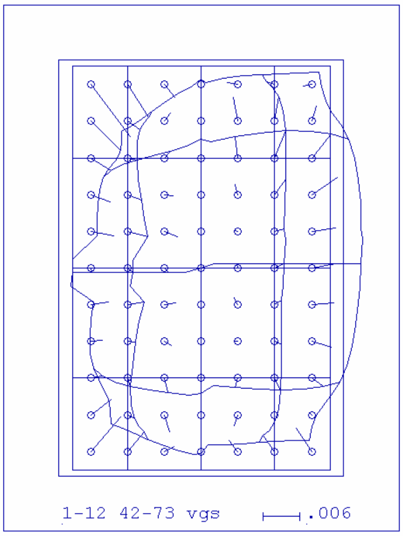

Figure 5 - Influence of UltraCamD additional parameters and BLUH standard parameters to image coordinates (units of the scale – mm)

5. GPS/IMU DATA INTEGRATION

The integration of the delivered GPS/IMU data in the study was everything but peaceful. After having confirmed that the direct import of the data in ISSD caused intolerable y-parallax in the block, the first impulse was to compute an integrated sensor orientation in order to adjust the angles to the automatic determined photo coordinates. A comparison between the exterior orientation parameters resulting from the AT and the GPS/IMU values revealed flight direction dependent shifts of approximately ±25 m in Xo and ±5 m in Yo for every strip except for the last one (Fig. 6). The Zo values were similar in both data sets. As for the angles, they revealed no flight direction dependent systematic, having the differences for the last strip a different amount.

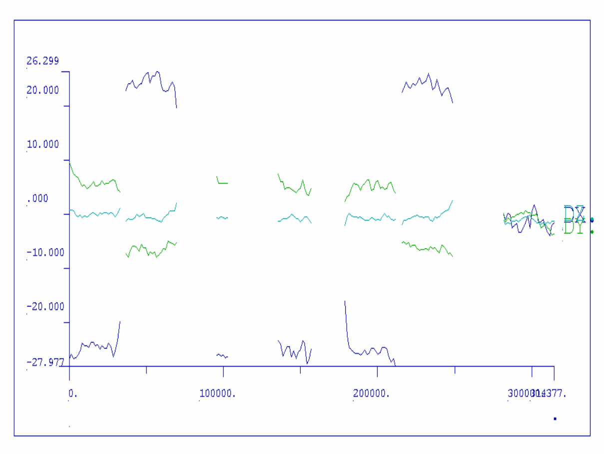

Figure 6 - Differences between AT-projection centers and GPS/IMU data (m)

Assuming the results from the AT as a reference, the sub-block containing the 5 upper strips has been shifted, each strip independently, and corrected from the misalignment. The last strip has only been corrected from the respective misalignment. An integrated sensor orientation has been applied to the corrected GPS/IMU data, adjusting these to the photo coordinates set, and an intersection has been calculated to obtain object coordinates of the homologous points. Table 3 shows the discrepancies to check points.

	Number of check points	SX (m)	SY (m)	SZ (m)
BLUH	68	0.738	0.635	1.300
1. ISSD	50	23.825	5.238	1.397
2. ISSD (PPA=(0,0))	71	0.884	0.684	1.147

Table 3 - Discrepancies at check points after correction of GPS/IMU data

The first trial to measure the discrepancies at check points by means of ISSD revealed for the upper 5 strips a symmetrical behaviour to the one seen during the calibration. The check points were shifted in the opposite direction as projection centres were. After a change in the camera definition file for the upper strips the differences in the object coordinates measured in ISSD became similar to those calculated in BLUH (table 3, last line). This fact made clear how strong the interior orientation parameters influence the direct georeferencing. The values obtained by BLUH do satisfy the requirements for mapping in scale 1:25000 (SX, SY =< 2.5 m SZ =< 3.3 m). The intolerable y-parallax also vanished in the entire block allowing stereo plotting. Nevertheless, a real direct georeferencing of the photos couldn't be done under these conditions, since the given GPS/IMU data had been completely changed.

6. CAMERA CALIBRATION DATA

The undoubted cause for the shifts of the projection centres in X and Y was not obvious from the available data and information, but the flight direction dependent systematic could indicate an incorrect interior orientation. The amounts of the shifts seemed too big to be caused by an antenna offset or a synchronization error. An unintentional use of the wrong settings in the ISSD was also possible.

Several trials were undertaken to locate the origin of the problem assuming now the GPS/IMU data as a reference instead of the AT results. First it was investigated whether the actual photo coordinate system could be rotated in relation to the system of the given PPA. This would change the signs and switch the values of xo and yo. Four cases were analysed (rotation of 0, 90, 180, 270 degrees clockwise) and the photo coordinates of the 5 upper strips were transformed accordingly. The RMSE at control and check points after bundle triangulation in all cases were in sub-pixel domain (table 4), showing the rotation of 180º better results in Z.

Rotation CW	RMSE (m)			σo (μm)
	X	Y	Z	
0º	0.358	0.307	0.615	4.6
90º	0.331	0.344	0.428	4.6
180º	0.402	0.346	0.385	4.7
270º	0.335	0.428	0.418	4.6

Table 4 – RMSE at control points after ATs with rotated photo coordinates system

The analysis of the calculated exterior orientations instead, revealed important differences from case to case. Comparing with the GPS/IMU data, the mean shift values in table 5 were obtained for the 5 upper strips showing the still existing flight direction systematic.

Rotation CW	Shift X (m)		Shift Y (m)	
	K=0grd	200grd	0grd	200grd
0º	-24.55	25.43	5.49	-4.20
90º	4.64	- 4.58	-15.20	15.49
180º	24.29	- 23.25	14.73	-15.33
270º	- 4.44	6.28	36.13	-35.79

Table 5 – Mean shift values between AT and GPS/IMU orientations with rotated photo coordinate systems

Since none of the results was satisfying for a direct georeferencing, a second hypothesis was advanced: the photo coordinate system has the right orientation but the given PPA values don't correspond to these strips (wrong calibration data). To find the values for the PPA that simultaneously guarantee projection centre shifts and RMSE at check points within the tolerance, would allow the direct georeferencing of the photos in the photogrammetric workstation. Table 6 shows the shifts corresponding to a PPA equal (0,0) and to a synthetically generated PPA. This one was obtained by transforming the Y- shift occurred with PPA = (0,0) to the image scale, since the relation between yo and Y-Shift seemed to be quasi-linear.

PPA (synthetic)	Shift X (m)		Shift Y (m)	
	K=0grd	200grd	K=0grd	200grd
(0,0)	-0.265	1.225	9.98	-9.697
(0,-0.175)	0.411		0.617	

Table 6 – Mean shift values between AT and GPS/IMU orientations with synthetic PPAs

The flight direction dependent systematic disappears with the new PPA.

A set of photo coordinates with strips 1 to 5 referred to this PPA and strip 6 unchanged was used for an integrated sensor orientation of the original GPS/IMU data. This was followed by an intersection. The discrepancies at both sets of check points are shown in table 7.

Check points	Number of points	SX(m)	SY(m)	SZ(m)
1. Set	74	0.524	0.426	0.817
2. Set	67	0.548	0.464	0.698

Table 7 – Discrepancies at check points after intersection using GPS/IMU data

These results were better than the previous, enforcing the thesis of the incorrect delivered calibration data for the northern strips.

For the new set of photo coordinates, an analysis of the remaining y-parallax after pair wise intersection was done using both the given GPS/IMU data and the resulting orientation values after the integrated sensor orientation (Fig. 7). For stereo plotting this was a relevant item.

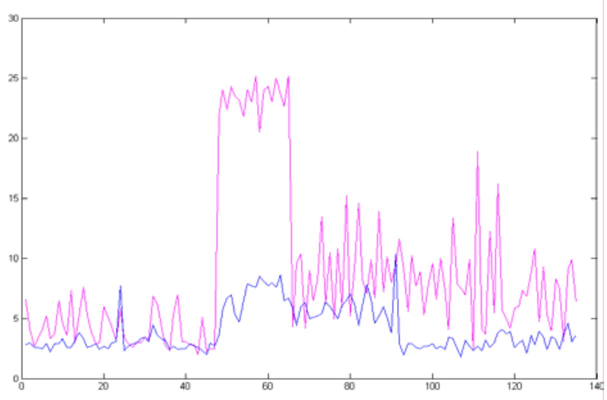

Figure 7 – Remaining y-parallaxes in the models (in µm).
Magenta: using given GPS/IMU
Blue: after Integrated Sensor Orientation

With the given GPS/IMU data as exterior orientations, the remaining y-parallax (Fig.7 in magenta) is merely greater than 20 µm in the models of the third strip (photos 45 to 65), presenting very similar values along the strip. 20 µm is a conventional y-parallax upper limit for the human stereoscopic perception. The third strip is the one with the gap, so it is possible that the camera or the GPS/IMU system weren't working properly during the flight. The parallaxes after the Integrated Sensor Orientation (Fig.7 in blue) are clearly smaller in all models, not exceeding 10 µm.

7. CONCLUSION

From the pursued analyses to the sub-block coming from the digital coverage of Portugal done from 2004 till 2006, consisting of 6 parallel strips with 142 digital photos acquired with a Vexcel UltraCamD, with a scale of approx. 1:56 000 (GSD ≈ 0.5 m) and a base to height ratio of 1: 3.8, it could be following concluded:

- The visual quality of the images for interpretation and object identification are adequate for the pretended mapping in scale 1:25000.
- For the same rectangular area 58% more models have to be stereo plotted than in the usual workflow (analogue photos in scale 1:25 000)
- Supported in ground control points, the block geometry allowed a precision of approx. 1 GSD in X and Y and 0.15‰ of flying height in Z
- Special UltraCamD additional parameters used in BLUH revealed systematic influences in the synthetic image attaining more than one pixel in certain regions.
- The given PPA coordinates for the camera corresponding to the five northern strips and the given GPS/IMU data, were not compatible, producing flight direction dependent shifts of +/- 25 m in X and +/- 5 m in Y.
- With a synthetic determined PPA for the camera of the northern strips, a direct georeferencing with tolerable y-parallaxes was possible for all strips excepting the third.
- A gap corresponding to 2 successive images and the y-parallaxes in all models of the third strip straitens the use of this strip for stereo plotting.
- An integrated sensor orientation applied to the given GPS/IMU data and to the new photo coordinate set (strips 1 to 5 with PPA(0,-0.175), strip 6 with PPA(0,0)) would allow the stereo plotting of all models, including strip 3.
- After an integrated sensor orientation the discrepancies at check points are about 1 GSD in X and Y and 0.13‰ of flying height in Z.

These results led to the conclusion that direct georeferencing of sub-blocks from the digital coverage for stereo plotting is generally feasible for mapping in scale 1:25 000. Some strips have problems of gaps and of disturbing y-parallaxes. Gaps can't be solved unless the flight is repeated. Remaining y-parallaxes can be reduced also in these strips by an integrated sensor orientation. Calibration data delivered with the sub-block was not compatible with the GPS/IMU data, raising doubts about its reliability.

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