ESTABLISHING A CAMERA-IMU CALIBRATION PROCEDURE FOR THE SPANISH NATIONAL ORTOPHOTO PROGRAM

D.A. Nafría [a], B. Arias [b], V. Blanco [a], O.O. Rodríguez [a], M. Blanco [a], F.J. Antolín [a], J. Gómez [c]

[a] Castilla y León Agricultural Technological Institute (ITACyL)
Carretera de Burgos-Portugal km 119, 47071, Valladolid Spain – nafgarda@itacyl.es
[b] Dept. of Cartographic, Geodesic Engineering and Photogrammetry
León University, Avenida de Astorga, Ponferrada, Spain – benjamin.arias@unileon.es
[c] School of Geodesy and Cartography Engineering, Salamanca University
Hornos Caleros 50, Ávila, Spain – fotod@usal.es

KEY WORDS: Accuracy, Calibration, Camera, GPS/INS, Direct Georeferencing, Orientation, Orthoimage.

ABSTRACT:

Since 2004 the Spanish National and Regional Governments are producing aerial orthophoto coverages renewed every two years. The Castilla y León region has introduced some modifications in the production schema in order to abbreviate the orhophoto delivery date. Year in, year out modifications in the exterior orientation procedure has been done and the spatial accuracy results has been improved according with the tests carried out by the quality assessment team. In 2007 the regional government built a calibration field in order to compute the most suitable minsalignment parameters for Direct Orientation. Using the calibration field the spatial accuracy obtained by Direct Orientation almost covers the national technical specification written for bundle adjustment (RMSE = GSD for X, Y and Z). The Integrated Sensor Orientation applied in images from digital frame cameras has proved an improvement in the spatial accuracy respect the traditional L1 GPS supported bundle adjustment applied to scanned images from film cameras.

1. INTRODUCTION

1.1 The orthophoto program

The Agricultural Technological Institute of Castilla y León (ITACyL), which is part of the Castilla y León regional government (Department of Agriculture), is developing the so called Spanish National Program for Aerial Orthophoto (PNOA) inside its regional boundaries. In accordance with the decentralized organization of Spain into 19 Regional Governments, PNOA is defined from the beginning as a decentralized yet coordinated project (Villa, 2008). The Regional Government is responsible for the orthophoto production while the National Government acts as coordinator by means of the Instituto Geográfico Nacional (IGN). Both organizations are funding the program.

Castilla y León is the largest region in Spain and one of the largest subdvisions in the European Union. It covers an area of 94,223 km² with an official population of 2.5 million. Since 1999, before the beginning of the PNOA program, several coverages of digital orthoimages had been taken by the regional government. When the PNOA started in 2004, a new production schema was set up: every year ¼ of the region area is flown in 0.25 m GSD and other ¼ is flown in 0.50 m GSD. Around 50,000 km² are flown by different contractors every year, which comes to approximately 30,000 images per year. Under this approach, the full orthophoto coverage is renewed every two years, yet the 0.25 m GSD collection, which images are also used for 1:5.000 mapping, is achieved within four years.

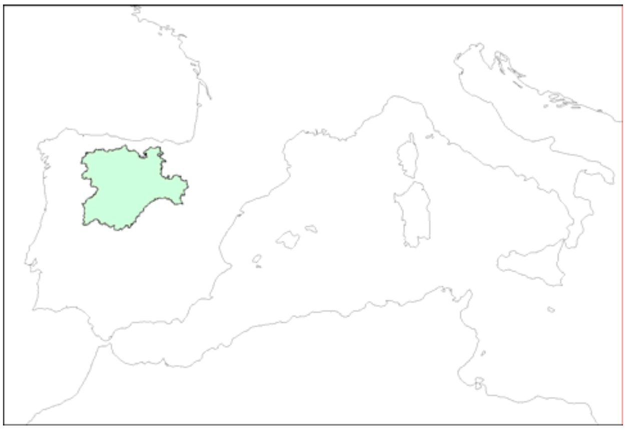

Figure 1. Castilla y León location in Europe

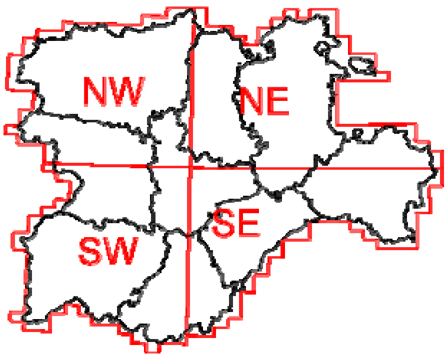

Figure 2. The region is divided in 4 quadrants. Since 2004 every year two quadrants were flown.

1.2 Production organization

As usually in civil service there is not staff enough to afford this kind of jobs and most of the task should be done by contractors. The regional government carries out call for tender for the orthophoto production and most of the Spanish aerial surveys companies are put in charge for the photogrammetric flight. The tests exposed in this paper have been done using the work done from contractors such BLOM-TASA, AZIMUT and STEREOCARTO. All the works have been done with digital frame cameras.

According with the production schema, if the orthophoto is renewed every two years, the government should be able to publish the orthophoto within the year in order to capitalize the product novelty. As long as the images are taken in summer, the orthophoho mosaic must be ended before the end of the year.

The ITACyL also is leading an initiative to publish On The Fly Orthophoto using the Open Geospatial Consortium Web Map Service standard. The aim of this project is to provide the users with a quick version, less accurate, of the orthophoto within one week since the photograph is taken. The aerial images are put together with the direct orientation and the pre-existing DTM in the WMS server. A standard WMS client is able to ask for the orthophoto inside an envelope, then the server locate the most suitable image; resample it accordingly with the client map screen resolution and orthorectify it. The Spanish company SIGRID is the responsible for the development of the so called SIGRIDWMS Server software.

In this timeless context, the Direct Orientation and Integrated Sensor Orientation procedures are essential in order to achieve a great reduction in the processing time without loosing, or even increasing, spatial accuracy in the ortophoto production.

1.3 Accuracy requirements

Within the roles of the PNOA program, one of the main tasks of the Spanish IGN is to set up a common specification for the decentralized production in order to achieve a standard quality across the country. However the PNOA general specifications have not set special remarks concerning the direct georeferencing and the Integrated Sensor Orientation techniques because the methodology has been based in aerial GPS assisted bundle adjustment; therefore the ITACyL has developed their own specifications keeping the final accuracy standards.

In the PNOA program, the orthophoto spatial accuracy is one of the main targets due its multipurpose use across public and private sector. The expected orthophoto accuracy, according with the specifications is better than twice GSD (Ground Sample Distance) computed in RMSE independently by X, Y axis, which is cheked by GPS ground check points. Moreover the orientation phase has a stronger accuracy requirement so the RMSE should be less than one GSD for X, Y and Z. Obviously the Z coordinate is the limitation.

2. FIRST EXPERIENCES WITH GPS/INS

2.1 Large format digital cameras arise in Spain.

When the PNOA program began by 2004 there were no digital cameras in Spain so analog cameras were used and films were scanned in 14 microns resolution. Moreover the IMU equipment was not available in most contractors and the usual orientation procedure was based in GPS supported bundle adjustment using L1 GPS receivers, with relative solution per strip, and crossed strips along the coverage area.

During 2004 the firsts UltracamD cameras arrived to Spain and the ITACyL, in joint venture with BLOM-TASA, underwent a test project focussing in managing the new sensor and to gather experience to introduce the digital cameras and the INS in the PNOA program. The first project area, a small river basin, was covered by 76 photos and 26 control/check points. Apart from learning how to deal with the digital camera, this test brought us reach some conclusion: 1) If there were good enough GPS positions, ground control points were not worth it. 2) Results matching 8 bits vs. 16 bits images in AT were enough similar to keep using the 8 bits version.

2004 was the last year film cameras were used in Castilla y León so it was the end of a technology. As an example a 16,000 km² orthophoto block, from a 1:20,000 analog flight (0.25 m GSD), reached a spatial accuracy of 0.25 m and 0.35 m in X and Y respectively. The spatial accuracy is expressed in RMSE independent by coordinate and was computed from 70 check point. This project was very intensive in field work so the target was to reduce this work in future, keeping the spatial accuracy.

2.2 PNOA program begin using the GPS/INS.

In 2005 only digital cameras with GPS/INS equipment were used in PNOA. For that year the main goal was to compute the orientation without control points for the 0.50 m GSD project using the Integrated Sensor Orientation technique. However there were not GPS reference stations in the region and the contractor needed to deploy several reference stations along the project area. As an example the spatial accuracy results are showed in 0The orthophoto accuracy results were better than the ones obtained in 2004.

Product (Check pts.)	RMSE X (m)	RMSE Y (m)	RMSE Z (m)
ISO without control points (107)	0.31	0.32	0.48
Orthophoto (Based in ISO) (47)	0.34	0.43	---

Table 1. Accuracy results from 2005 0.50 m GSD project (Block 2, 6,500 km2) without control points.

At the same time the 0.25m GSD project was performed in a more classical environment with cross strips and field work due to the lack of GPS infrastructure in the region. However one block near a GPS reference station was used as test bed to compare the results using Direct Orientation and Integrated Sensor Orientation. Moreover the influence in the distance between the aircraft and the Reference Station were studied. 0 and 0show the differences obtained between the direct orientation and the ISO.

The results show the effects of a pour procedure for the IMU-Camera calibration that more or less was solved in the AT. For this project the contractor had calculated the minsalignment at the flying height using 18 images in three strips taken inside the project as it is showed in 0. Several authors like Mostafa (2002) address the importance of the calibration procedure to get good enough exterior orientation parameters. On the other side, according with 0, the experience testing the control needs showed again that with good GPS/INS data, even being out of alignment, the amount of control points were indifferent.

Product (Check pts.)	RMSE X (m)	RMSE Y (m)	RMSE Z (m)
Direct Orientation (41)	0.23	0.67	1.24
ISO without control points (41)	0.14	0.15	0.36

Table 2. Results from 2005 0.25 m GSD project (Block 2 without control points.

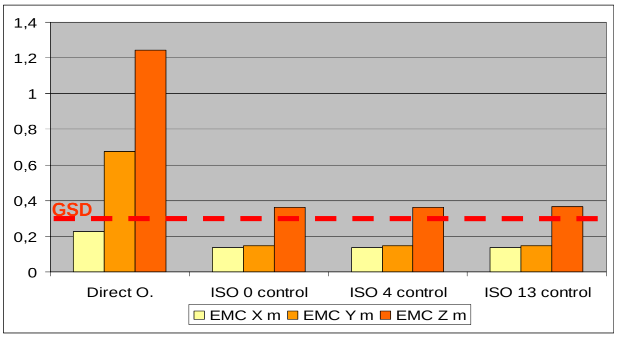

Figure 3. Results from 2005 0.25 m GSD project (Block 2) without control points.

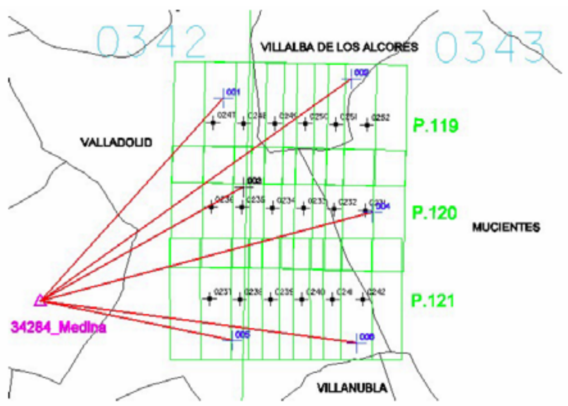

Figure 4. Calibration flight 2005 0.25m GSD project.

Also during 2005 the distance between the plane and the GPS reference station was tested. At that moment this point was one of the principal difficulties for direct orientation due to the lack of GPS infrastructure in the region. The test results in 0show the differences between the photocenters calculated using a GPS reference station close to the block (Valadolid city) against a reference station 110 km far away from the block (Logroño city). The results in concordance with LooD., (2003) show that there was almost no difference between both calculations so there were some flexibility using sparse reference stations, at least while the ionospheric conditions were moderate.

Parameter	X (m)	Y (m)	Z (m)
Mean error	0.0026	0.0006	0.0894
RMSE	0.046	0.043	0.118
Maximun error	0.118	0.147	0.238

Table 3. Results from 2005 0.25 m GSD project (Block 2. Diference between photocentres calculated from Valladolid GPS reference station and Logroño GPS reference station (110 km away) using GPS Aerocontrol IId equipment and GravNav v 7.

According with 0in the Z coordinate there was a systematic error between both calculations derived from an error in the reference station antenna calibration. This is an important topic and an easy mistake when the GPS data is processed. Unfortunately the Direct Orientation is weak against this situation due to the lack of redundancy, so it is important to be careful processing the data, we are saving time but there are some risks.

For the 2006 projects the IMU-Camera calibration was established as an important question inside the 0.50 m GSD project in order to reach the expeted accuracy in the orientaton, so the calibration flight were done following this guidelines:

- Special flight with 0.10m GSD close to a reference station
- Flight designed with 6 strips with 15 images per strip
- Natural check points measured with GPS
- Computation of exterior orientation parameters applying scale factor and false northing.
- Computation of minsalignment angles removing the first and the last images from every strip.

Following this guidelines the results in direct orientation were improved from the previous year as it is show in 0

Product (Check pts.)	RMSE X (m)	RMSE Y (m)	RMSE Z (m)
Direct Orientation (120)	0.54	0.56	1.08
ISO without control points (120)	0.18	0.18	0.30
Orthophoto (Based in ISO) (139)	0.38	0.418	--

Table 4. Results from 2006 0.50 m GSD project (Block 4, 6,080 km2) without control points.

However the results were not good enough in Direct Orientation according with the orientation requirements (RMSE < GSD for X, Y and Z). Therefore a new step should be done in order to achieve the target: It was necessary to build a presignalized calibration field.

3. THE VALLADOLID CALIBRATION FIELD

In the beginning of 2007 a calibration field was designed and built in order to calibrate and asses the airborne sensors: digital camera, GNSS equipment and INS.

The purpose of this job was to create a calibration procedure using this field and do it mandatory for all our contractors. In addition all the data collected would be accessible to anyone interested in research activities.

A bibliographic revision has been carried out to design the size of the field in order to support 3 types of calibration flights (Comprehensive or area based, cross and "I"block) according with Honkavaara (2004).

The calibration test field is 3.6 x 3.6 km long and is located in the outskirts of Valladolid, central Spain. Nineteen targets are placed in the test zones. As is showed in 0the targets are made of reinforced white concrete with one corner rounded that is always pointing to the north in order to check accidental movements.

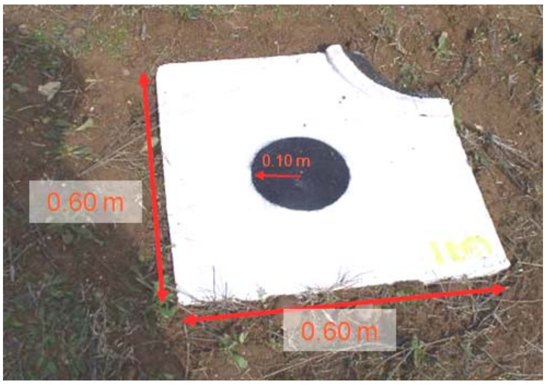

Figure 5. Presignalized target used.

Inside the calibration field there is a EUREF L1&L2 GNSS (GPS+GLONASS) reference station with 1Hz logging rate. In addition there are other 10 reference stations within 100 km from the calibration field. This amount of GNSS data make the test site interesting for other purposes related with the GNSS trajectory processing techniques and their expected accuracy.

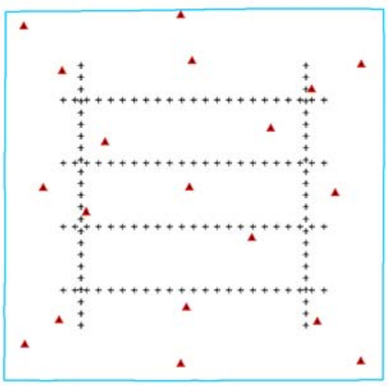

Figure 6. The Valladolid Calibration Field ground points distribution.

4. CALIBRATION TEST FLIGHTS

Once the calibration field had been built, the calibration flights were projected to allow the 3 types of calibration procedures mentioned above. As a result, 5 longitudinal strips and 3 transversal strips were flown (two of each with full overlap and opposite sense). Provided that one of our goals is to asses both the GPS-IMU lever arm and the principal distance and due to the lack of relief in the zone, it becomes a must to acquire and to process images from different flying heights. Therefore two different flying heights have been projected with GSDs of 0.075 m and 0.150 m. Moreover evaluate the most convenient GSD to achieve our accuracy requirements using a single height flight is also a goal. The photocentres for both heights are exactly in the same X and Y so the overlaps changes according with 0

GSD (m)	Forward	Sidelap
0.075	80%	35%
0.15	90%	65%

Table 5. Overlaps for the two flying .heights.

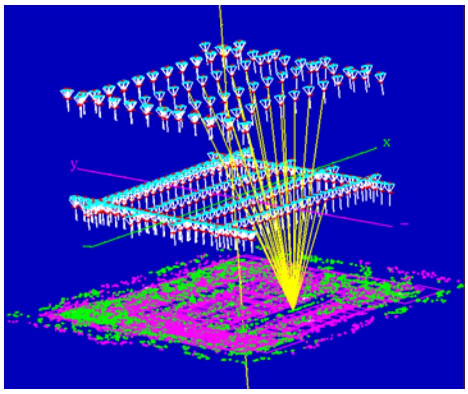

Figure 7. Calibration flight schematic representation obtained with BINGO 5.4.

During the 2007 campaign the calibration field was flown 6 times using 3 different cameras from different contractors. All the cameras were UltracamD. Only the first two flights were done with all the strips, including the two heights, focusing in scientific research and assessing the most affordable calibration procedure. The rest of the calibration flights where done with just 4 longitudinal strips for calibrating in a production environment. The shape of the strips is depicted in Figure 8.

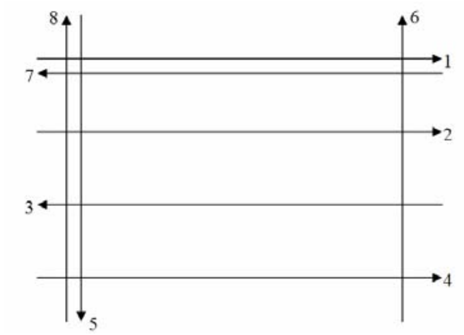

Figure 8. Configuration of strips flown at two flying heights. Strips 1 and 7, and strips 5 and 8 are double, strips with the same trajectory but with opposite directions.

4.1 Measures

Measures, both manual and automatic, were performed with Match-AT, v.5. The point measurement was done for the whole block with both heights, all strips together, so it is possible to assure the same image coordinates for all the calibration procedures. To guarantee a reliable computation of the bundle adjustment of both flights, about 100 tie points were manually measured on each of them.

Afterward the strips were selected according with their respective distribution in the block configuration and the bundle adjustment was performed.

4.2 Computation

The computation of the Aerotriangulation has been done with Bingo v.5.4. The estimated parameters for each calibration flight type were: Focal distance, principal point, Camera-IMU boresight, constant shift and additional parameters.

4.3 Principal distance

The main reason to include the two heights in the calibration was the possibility to discriminate between an error in the GPS-IMU lever-arm and an error in the principal distance. Therefore assuming the lever-arm is correct, as it is usually, we should check the principal distance in a bundle adjustment with the information derived from the two flying heights. The results are collected in 0

Unknown	*c*
c	101,3968
S_c	0.0018
σ_0	0.72

Table 6. Results of the computation of the principal distance, where c: principal distance; S_c, standard deviation; σ_0; sigma naught of the bundle adjustment (Arias et al. 2008).

Checking these results, the autocalibrated principal distance is close to one expressed in the calibration certificate, specially if the standard deviation is taken into account. Therefore the principal distance it is not a problem at least at those flying heights. In future should be possible to identify a shift in Z as an error in the GPS-IMU lever arm without doubting about the principal distance.

4.4 Future developments

The amount of data collected in the calibration field allow future research in aspects related with the camera calibration, such the works done by Arias et al. (2008), and minsalignment computations using different flight configurations like the OEEPE 2002 test.

4.5 Production results

The main goals of the PNOA program is produce and publish the orthophoto on time. Therefore for production purposes a simplified version of the calibration flight was used. Only four longitudinal and two crossed strips were used following a comprehensive block definition and the ground points were used as check.

The 0shows the 2007 production results for a block. As it is exposed, the spatial accuracy has been improved compared with the 2006 data yet the obtained RMSE Z for Direct Orientation is just exceeding the established requirement (< GSD)

Product (Check pts.)	RMSE X (m)	RMSE Y (m)	RMSE Z (m)
Direct Orientation (120)	0.38	0.28	0.51
ISO without control points (70)	0.17	0.16	0.24
Orthophoto (based in ISO) (94)	0.33	0.34	--

Table 7. Results from 2007 0.50 m GSD project (Block 4, 5,700 km2) without control points.

4.6 The 2008 campaing

For the 2008 projects, the calibration flight will be done at the beginning of the project and will be repeated as usual if the photogrammetric equipment is moved from the plane. It will be flow only at one height, around 0.10m GSD. Four longitudinal strips and two crossed will be done, assuring always the equilibrium between the senses.

As long as the UTM is the projection used for mapping purposes in the PNOA program, the calibration will be done in that projection. According with several authors, including the OEEPE results (Heipke et al. 2002) a tangential coordinate system is recommended, but the results showed by Yastikli (2004) and Mostafa (2002) reveal that using UTM are good enough and simplify the job. As we will use the UTM, the exterior orientation parameters will be calculated applying projection scale factor in Z and the false northing correction in kappa according with Jacobsen (2004).

5. CONCLUSIONS

The works performed during the last four years within the PNOA program in Castilla y León has demonstrated de goals and the limitations of the Direct Orientation and the ISO in a production environment. The Direct Orientation spatial accuracy has been improved significantly and is close to the established requirements for exterior orientation using bundle adjustment. Also the orthophoto spatial accuracy has been improved yet the production waste of time has been reduced dramatically due to the ISO technique.

REFERENCES

Arias, B., Nafría, D.A., Blanco, V., Rodríguez, O.O., Blanco, M., Antolín, F.J., Rodriguez, J., Gómez, J. Testing a Digital Large Format Camera. In Proceedings of the International Calibration and Orientation Workshop EuroCOW, 30th January- 1st February 2008 Castelldefels, Spain.

Heipke, C., Jacobsen, K., Wegmann, H. (2002). Analysis of the results of the OEEPE Test Integrated Sensor Orientation.
Heipke C., Jacobsen K., Wegmann H. (Eds). Frankfurt am

Main – Germany. OEEPE Official Publication n° 43, 2002, pp. 31-49.

Honkavaara, E., 2004. In-Flight Camera Calibration for Direct Georeferencing. In: Proceedings of the XXth ISPRS Congress, 12-23 July 2004 Istanbul, Turkey.

Honkavaara, E., Ahokas, E., Hyyppä, J., Jaakkola, J., Kaartinen, H., Kuittinen, R., Markelin, L., Nurminen, K., 2006. Geometric test field calibration of digital photogrammetric sensors. In: *ISPRS Journal of Photogrammetry & Remote Sensing*, Vol. 60, pp. 387–399.

Jacobsen, K., 2004. Direct Integrated Sensor Orientation - Pros and Cons. In: Proceedings of the XXth ISPRS Congress, 12-23 July 2004 Istanbul, Turkey.

Kruck, E., 2007. User's Manual BINGO v.5.3.

Mostafa M., 2002: Camera/IMU Boresight Calibration: New Advances and Performance Analysis. http://www.applanix.com/media/downloads/products/articles_papers/POSAV_2002_04_CameraIMU_Boresight.pdf (accessed 15 Jun. 2006)

Loo D., 2003: Using CORS/IGS Base Stations for Airborne Surveys. http://www.waypnt.com (accessed 15 Jun. 2006)

Villa, G., 2008. Spanish National Program for Aerial Orthophoto: Collaborative and Innovative Spirit in Geospatial Information. *Geoinformatics*, http://www.geoinformatics.com-/asp/default.asp?t=article&newsid=3636 (accessed 30 Apr. 2008)

Yastikli, N., 2004. The effect of system calibration on Direct Sensor Orientation. In: Proceedings of the XXth ISPRS Congress, 12-23 July 2004 Istanbul, Turkey.