ACURACY ASSESSMENT OF PROJECTS PERFORMED BY SAAPI SYSTEM

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ABSTRACT:

The use of digital cameras for photogrammetric applications, especially in aerial mapping is a recognized trend due the advances in sensor resolution and other hardware and software components. Nowadays, there are some models of cameras with 50 and 60 megapixels, with advantages because of their flexibility and cost effectiveness, which provide ground coverage near to classic photogrammetric film cameras. This type of cameras can also be integrated to GPS/INS systems, with specially designed mechanic mounts and electronics devices that can control all components of the aerial mapping system. Several custom designed systems have been used worldwide with excellent results for mapping applications. In this context this paper presents the results obtained with SAAPI system in a huge project, the digital mapping of Bahia State, Brazil. This system is an airborne acquisition system based on professional Hasselblad digital frame cameras integrated to direct orientation sensors (GPS/INS), electronic devices and hardware and software tools. In order to assess the geometric accuracy of this mapping system a set of images acquired by SAAPI with a ground sample distance (GSD of 80 cm was used. This block with 2997 images distributed in 48 strips was processed with INPHO MATCH-T. Several experiments were carried out to assess accuracy improvements in the object space coordinates when considering in-situ calibration bundle adjustment with direct georeferencing. Moreover, orthophotos and DTM products were generated using the INPHO-MATCH-T software and analyzed. It was verified that suitable accuracy was achieved rounding 1 to 1.5 GSD in the final products. These results showed that this type of aerial system can be successfully used for mapping projects, provided that rigorous photogrammetric processing workflow is used.

1. INTRODUCTION

With the recent developments in the technology of optical digital sensors, the use of professional digital frame cameras emerged as an alternative for aerial photogrammetric applications in the latest years. The main reasons are the flexibility and cost effectiveness, when compared to film cameras and high-end digital systems. Nowadays, this practice has been considered as an acceptable technique, and some countries (like EUA and Canada) are preparing guidelines and specifications for the use of this category of camera in photogrammetric works.

Compared to classic film cameras (230 x 230 mm format) or high-end digital systems, the professional digital frame cameras have smaller ground coverage area, although this scenario is rapidly changing with the new versions of the sensor resolution (50-60-80 Mpixels). On the other hand, the professional digital cameras allow the development of light weight and low cost aerial photogrammetric systems.

Due to this favourable cost/benefit ratio, many companies have adapted with success professional digital frame cameras to produce aerial mapping systems, as DigiCam (IGI), DSS (Digital Sensor System – Applanix) and SAAPI (Lightweight Airborne Image Acquisition System - Engemap). Others independents systems based on this category of camera for different photogrammetric applications were previously implemented, as showed in Mostafa and Schwarz (2000), Habib et al. (2002), Roig et al. (2006) and Petrie (2009).

Within this context, this paper presents the geometric results achieved for a large block of images acquired by SAAPI in order to assess the geometric accuracy of this category of mapping system.

2. SAAPI SYSTEM

The SAAPI system (Lightweight Airborne Image Acquisition System) was developed by Engemap Company in Brazil, with UNESP partnership and FAPESP (The State of São Paulo Research Foundation) grant in the project first phase. This system is composed by an acquisition platform, control and power units (Figure 1).

The main features of the system are:
- RGB and Infrared professional digital cameras at same resolution - 50 megapixels each one (to be upgraded to 60 megapixels in the next months);
- Direct Georeferencing system;
- Specific rigid housing for the cameras;
- Autonomous system of triggering, high precision data synchronism and logging and storage in SSD (Solid State Disk);
- Software for automatic flight plan generation (integrated to the GPS and Google Earth), real time navigation and system control, and flight post processing data;
- Modular design: light weight (about 60 kg the complete system, including power unit) and less power consumption needs (12V). These features allow high
flexibility for installing the system in different kinds of aircrafts, mainly in small aerial platforms.

Figure 1. The SAAPI system.

The technical specifications of the cameras that compose the SAAPI acquisition platform are given in Table 1.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal length</td>
<td>50 or 35 mm</td>
</tr>
<tr>
<td>Pixel size</td>
<td>6 μm</td>
</tr>
<tr>
<td>Radiometric resolution</td>
<td>12 bit</td>
</tr>
<tr>
<td>Image size</td>
<td>8176 x 6132 pixels (50 megapixels)</td>
</tr>
<tr>
<td>Image size</td>
<td>49 x 36.9 mm</td>
</tr>
<tr>
<td>Approximated field of view - each camera (along/across track)</td>
<td>46°/59° - 50 mm lens</td>
</tr>
</tbody>
</table>

Table 1: Technical specifications of the cameras in SAAPI system.

Several aerial survey projects were performed with success by Engenmap Company in the latest three years with the SAAPI system, including urban and environmental mapping, highways, power lines and pipeline applications. These projects include cartographic mapping products generation in different scales, from 1:10000 (image resolution of 60-80 cm) to 1:1000 (image resolution of 10-15 cm).

Nowadays, the main projects that are being carried out by Engenmap Company in Brazil using the SAAPI system are:
- Bahia state mapping, where digital imagery over an area of 600,000 km² are being acquired with a GSD of 80 cm for DSM (Digital Surface Model) and Orthophoto generation;
- Santa Catarina state mapping: RGB and infrared digital imagery of an area of 97,000 km² with a GSD of 39 cm for DSM (Digital Surface Model), DTM (Digital Terrain Model), Orthophoto generation and hydrography restitution.

3. BACKGROUND

In general, camera calibration is performed before aerial surveying and the IOP (Interior Orientation Parameters) are usually estimated by laboratory methods or field method, including close range camera calibration. These parameters are constrained in bundle block triangulation, with the image coordinates being a priori corrected for the systematic errors (lens distortion, photogrammetric refraction and, less common, affine deformation). This solution leads to a more simplified bundle adjustment model, with less parameters to be estimated and without high correlations between the estimated IOP and EOP (Exterior Orientation Parameter)

The camera IOP (focal length, principal point coordinates, lens distortions, affine deformations) can be estimated during the bundle block adjustment based on the collinearity equations with additional parameters that can be written by using different model. Even knowing that the use of additional parameters can result in high correlations between parameters, it is important to consider the differences in the environmental conditions between the calibration field and the flight area. Moreover, the operation and the handling of the cameras during the flight projects can modify the inner geometry of the cameras (depending on the optical and sensor stability of the camera model) and this changes can affects the bundle reconstruction.

Generally polynomial models were used as additional parameters in bundle block adjustment. In this approach the focal length and the principal point coordinates are constrained with its a priori calibrated values and the polynomial coefficients aims at to absorb the residual systematic errors related to the lens distortion, shrinkage and other non modeled deformations. The process in which these models are used is generally known as self calibration and was developed in the seventies; nevertheless some authors argue that this term should be related to the camera calibration with a minimum set of constraints and even without ground control and that a better term should be in-situ or on-the-job calibration (Clarke and Fryer, 1998). Examples of groups of additional parameters are Ebner, Brown and Grun models (Muray et al, 1984; Mikhail et al, 2001; Clarke and Fryer, 1998).

It is of crucial important to analyze the correct use of these additional parameters groups for digital cameras, since that many errors existing in analog film cameras, like shrinkage or errors due to comparator measurements are unsuitable for digital sensors. In order to investigate this subject, some experiments using LPS (Leica Photogrammetry Suite) software, in which triangulation module was set to use additional parameters, were carried out. Images collected with a 39 MP Hasselblad digital camera were used. In the performed experiments it was verified that using only the radial lens distortion provided better results on the object space reconstruction than the polynomial models (Brown, Ebner, Bauer and Jacobsen). Details of these tests are presented in Ruy et al (2008).

In this context the experiments presented in this paper were carried out with bundle block adjustment performed by the INPHO package software (Match-AT, Match-T) with blocks of images acquired by SAAPI system. In these experiments the camera calibration parameters were computed in a small block with dense control points distribution and the entire block of images was processed with different control points configurations. Moreover it is presented the DSM quality achieved with this image block.

4. EXPERIMENTAL ASSESSMENT

In this chapter a set of experiments with bundle block adjustment and DSM generation with Bahia image block are presented. This block is composed by 2997 images distributed in 48 strips. The flight height was 4670 m, resulting in GSD (Ground Sample Distance) of 80 cm.
4.1 Bundle Block adjustment

For this block the processing and analysis were carried out with 127 GCPs (Ground Control Points) and 26 check points. The tie points were automatically measured in the INPHO Match-AT software, with a rigorous quality control. It was measured 1,092,365 points in the entire block. The GPS/INS shift/drift model error was used to absorb residual systematic errors in the camera positions, because of block dimensions.

In this work it is also assessed an approach that relies on the calibration in a sub-block with a dense control points distribution (See marked area in Figure 2). The IOP estimated in this sub-block are then used in the whole block, with a reduced set of GCP. Figure 2 shows the complete block of images related to the Bahia project as well as the ground control and check points distribution. In the left-up region is show the sub-block with dense GCP distribution.

The Bahia project is a large aerial survey project (600,000 km²) that is being developed by Engemap Company since 2009. The image block used in this study is located in south-west part of Bahia state in Brazil, as showed in Figure 3.

In order to assess the approach that uses a sub-block for computing the IOP an on-the-job calibration using 344 images (marked area in Figure 2) and 154 control points was carried out in the Match-AT INPHO software (In-Block module). The computed parameters are presented in the Table 2.

![Image 2](image2.jpg)

**Figure 2.** Complete block (2997 images) with control (127 points) and check points (26 points) distribution and a sub-block with control and check points distribution (marked).

![Image 3](image3.jpg)

**Figure 3.** Geographic location of the studied block of images.

Table 2: IOP parameters and their estimated standard deviations computed with on-the-job calibration using a sub-block of 344 images.

<table>
<thead>
<tr>
<th></th>
<th>f (mm)</th>
<th>x0 (mm)</th>
<th>y0 (mm)</th>
<th>K1 (mm²)</th>
<th>K2 (mm²)</th>
<th>K3 (mm⁴)</th>
<th>P1 (mm²)</th>
<th>P2 (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>35.645 ± 0.003</td>
<td>-0.065 ± 0.002</td>
<td>0.176 ± 0.002</td>
<td>-7.167 x10⁻⁶ ± 2.710 x10⁻⁶</td>
<td>5.958 x10⁻⁸ ± 6.501 x10⁻¹¹</td>
<td>-8.315 x10⁻¹² ± 4.821 x10⁻¹⁴</td>
<td>-5.729 x10⁻⁶ ± 5.433 x10⁻⁶</td>
<td>3.795 x10⁻⁰ ± 5.511 x10⁻⁰⁶</td>
</tr>
</tbody>
</table>

Table 3: RMS values of the discrepancies in the control and check points for the Bahia complete block (2997 images).

<table>
<thead>
<tr>
<th>Experiment</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS (m)</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0.222</td>
<td>0.199</td>
<td>0.188</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Points</td>
<td>0.208</td>
<td>0.195</td>
<td>0.176</td>
<td>0.086</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMS (GSD)</td>
<td>0.405</td>
<td>0.428</td>
<td>0.753</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Check</td>
<td>0.431</td>
<td>0.434</td>
<td>0.774</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Points</td>
<td>0.432</td>
<td>0.445</td>
<td>0.714</td>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>0.134</td>
<td>0.465</td>
<td>0.812</td>
<td>1.290</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.420</td>
<td>1.290</td>
<td>1.290</td>
<td>1.290</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.420</td>
<td>1.290</td>
<td>1.290</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.420</td>
<td>1.290</td>
<td>1.290</td>
<td>1.290</td>
</tr>
<tr>
<td>RMS (m)</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
<td></td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Check</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Points</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The experiments were performed with the IOPs computed in the sub-block (344 images) in order to assess the approach that computes the IOPs parameters using a sub-block of images with a dense control point distribution and applying later these IOPs in the complete block with reduced GCPs.

By analyzing Table 3 it can be verified that when the number of GCPs was reduced seven times (experiment D), the quality of the solution in the object space was kept, when compared to the experiment A that used all the GCPs. The accuracy in the 3D reconstruction was around 1/2 GSD in planimetry and one GSD in altimetry.
For the analysis of the experiments presented in this work it was verified that the IOPs computed in the sub-block can be successfully applied to the complete block with a considerable reduction of GCP, provided that the direct georeferencing system is used. In this case it was verified that one control point every 20 images on the same strip flight and one control point every 8 strip flights are enough to guarantee the quality of the solution.

4.2 DSM generation

The main product of the Bahia project that is being generated by Engemap Company is the DSM of the entire Bahia state with 5 m of resolution. Figure 4 shows an example of DSM generated for the studied area presented in this paper.

The quality control of the products is being independently performed by the official Cartographic Army agency in Brazil - DSG (Geographic Service Division). For this DSM resolution (5 m) the Brazilian norms establishes that 90% of the altitude values of measured points on the product must have error less than 2.5 m and the RMS errors have to be less than 1.8 m, when compared to the check points collected in the field.

For the quality control of the DSM related to the studied area presented in this paper, 111 check points were used by the DSG agency. The results are presented in Table 4.

![Figure 4. Example of DSM generated for the Bahia project.](image)

<table>
<thead>
<tr>
<th>Max. (m)</th>
<th>Min. (m)</th>
<th>Average (m)</th>
<th>RMS (m)</th>
<th>RMS (GSD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error</td>
<td>2.439</td>
<td>0.005</td>
<td>1.043</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Table 4: Results of the quality control in the studied block.

Considering the results presented in Table 4 it can be seen that the accuracy of the DSM is clearly compatible with the specifications of the project, with the maximum individual error in 2.4 m and RMS error around 1 m.

By definition the DSM is related to the surface of the terrain and the absolute altitude or elevation of the points above the terrain, as showed in Figure 5.

![Figure 5. DSM representation.](image)

It was verified by the results of the quality control of DSM that there was a small tendency in the values (see the average column in Table 4). This tendency was mainly positive, because the values of heights measured on the DSM are higher than the corresponding ones obtained by the geodetic instruments in field (check points). This bias can be explained, in part, by the smoothing effect of DSM due to buildings, trees and others entities above the terrain artefacts (see Figure 5). Then, if the check point for the quality control was collected near to these features a difference in the DSM model can be expected in the quality analysis.

5. CONCLUSIONS

This paper presented an outline of the SAAPI system that is a digital acquisition platform for photogrammetric applications composed by professional digital frame cameras in a modular design, with flexibility and light-weight that can be installed in different kinds of aircrafts and helicopters that can be used for fast mapping production.

The results obtained with the bundle block adjustment and DSM quality control showed that this type of digital acquisition system can be successfully used for mapping projects, provided that rigorous photogrammetric processing workflow is used.

One of the limitations of the digital professional frame cameras is the sensor dimension, which results in an increase of the number of images and measured points in the photogrammetric projects. Nowadays this limitation is becoming irrelevant due to the new sensors resolution of digital cameras (50-60-80 mpixels), the GPS/INS integration and the high performance of photogrammetric software available, like Inpho package, that
allow the fully automation and fast processing of the photogrammetric products.

6. REFERENCES


