PROCEDURES FOR FAST ORIENTATION OF LEICA ADS40 IMAGERY

V. Casella, M. Franzini, B. Padova

DIET, University of Pavia, via Ferrata, 1 - 27100 Pavia - Italy
(vittorio.casella, marica.franzini, barbara.padova)@unipv.it

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ABSTRACT

Every year environmental disasters such as storms, floods and earthquakes cause thousands of deaths and great deal of damage around the world; the price to pay in terms of human lives and material damages is always considerable. The scientific community is involved in the endeavour for preventing disaster, monitoring environmental problems and supporting rescue efforts.
Geomatics is heavily concerned with all the aspects of disaster management. The paper focuses on the Leica ADS40 digital camera as a tool for performing post-disaster rapid mapping: in particular, the direct georeferencing mode is analyzed. The camera's main characteristics are depicted. Three different case studies are taken into consideration. Productivity and geometric accuracy are assessed.

1. INTRODUCTION

Many different surveying systems are used to support disaster and crisis management: according to the sensor type, optical, radar and laser devices; concerning the platform carrying the sensor, terrestrial, airborne and space-borne. Within aerial optical sensors, many solutions are available, depending on the format of the camera used and on the aerial vehicle adopted.
Large-format digital aerial cameras can be effectively used for crisis management and present some advantages: very high acquisition rates, image quality, very accurate exterior orientation parameters (EOP) measured by GPS/IMU systems.
The ADS40 camera (produced and delivered by Leica Geosystems, Switzerland) and its successors, ADS40-SH52 and ADS80 can be useful for crisis management. They can operate at several thousand meters and the corresponding image footprint can be as large as 10 km, cross track; they acquire at the same time the panchromatic (PAN), RGB and near-infrared (NIR) channels, so that the panchromatic, colour and colour-infrared (CIR) images can be formed; finally they are equipped with very accurate and reliable GPS/IMU devices which directly measure EOPs.
Aerial imagery is sometimes perceived as expensive and slow. The first statement is questionable and can't be answered with a simple *yes* or *no*: it should be discussed by considering several parameters, but this is beyond the scope of the present paper. The second assertion is true only when ground control points (GCP) are used to determine the exterior orientation of the images. But the second and third generations of the ADS camera perform very well even without any GCPs: direct georeferencing usually shows accuracy figures within the pixel size.
Several examples can be found in literature, of the use of ADS40 imagery in the case of disasters.
The USDA (United States Department of Agriculture) has surveyed the areas affected by the hurricanes Katrina, Rita, Wilma and Ike. The Federal Emergency Management Agency (FEMA), and other federal Agencies, have used the Leica camera for post-disaster cleanup and restoration projects (USDA Website).
The New South Wales Department of Lands in Australia bought an ADS40 camera in 2007 and regularly uses the acquired images for rapid response mapping; they are mainly interested in thunderstorms which cause local flash flooding (Paudyal and Abernethy, 2009).
The last example considered (GeoConnexion Website, 2008) is from China where the ADS40 camera was used after the earthquake occurred in May 2008. Following the plan provided by the Chinese Academy of Science, the private company Taiyuan Aero Photography Co. acquired several blocks above Chengdu area in the Sichuan province. At the China Central Government Earthquake Salvation Centre, the images were visually inspected and a singular inscription was discovered, on a rooftop in the village of Cao Ping: "SOS700". Thanks to this image the Chinese rescuers were able to save seven hundred people.
The paper focuses on fast orientation methodologies for the Leica ADS40-SH52 camera, therefore the direct georeferencing methodology is uniquely considered. Mainly, geometric accuracy is investigated.
Three datasets are taken into consideration. Some images are shown, which were acquired above the L'Aquila area immediately after the April 2009 earthquake. Some info was collected from people of the BLOM-CGR Company, which was in charge of the flights, so that an estimation of productivity and response time can be provided.
A second dataset is analyzed, covering a large area corresponding to a significant part of an Italian region. This block demonstrates which support can be given by the ADS40 in the case of widely hit areas. Productivity, in terms of square kilometres acquired per hour of flight, is assessed, as well as geometric accuracy. Finally a block covering Pavia's Test Site is analyzed. Owing to the availability of a large set of artificial ground control points, precisely measured, geometric accuracy is analyzed in a very reliable way.
Section 2 illustrates the camera's architecture and operating principle. Section 3 concerns the three datasets considered: some estimations and experiences are discussed, regarding productivity and delivery time of maps. Section 4 deals with Pavia's test site, used for one of the case studies. Finally, Section 5 shows geometric accuracy results.

2. THE SECOND GENERATION LEICA ADS40 CAMERA

The ADS40 characteristics are summarized in the following. Productivity issues are taken into consideration and an interesting GNSS positioning mode is also mentioned: precise point positioning (PPP). It is useful when the camera operates in areas not equipped with geodetic and positioning infrastructures.

2.1 Structure and operating principle of the camera

The Leica ADS40 camera is based on the pushbroom concept and is equipped with linear sensors. It has just one lens so that the several lines acquired in a certain time are taken from the same position and through the same optics. The camera acquires a unique very long image, for each viewing angle, nadir, forward and backward. The images produced are sometimes named pixel carpets, and are shown in Figure 1.

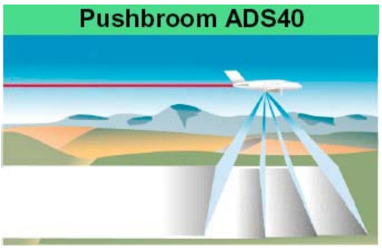

Figure 1. The pixel carpets produced by the Leica ADS40 camera.

The camera considered in the paper belongs to the second generation and is equipped with the SH52 sensor head, whose focal plate is illustrated in Figure 2. The camera focal length is 62.77 mm; the CCD arrays are constituted by 12000 elements of 6.5 microns; the whole sensor width is 78 mm; the nominal FOV is 64°. Twelve linear CCD arrays are located on the focal plane of the camera: the forward looking array has a 27° viewing angle and is constituted by only a panchromatic sensor; in the nadir position there are four arrays working in the red, green, blue and near-infrared bands; two more panchromatic arrays have a viewing angle of 2°; finally, in the backward looking position, there are four lines (RGB and NIR) having a 16° angle and another panchromatic array having 14°.

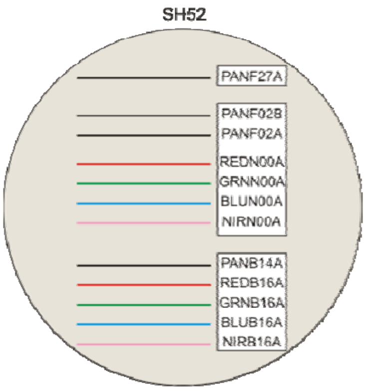

Figure 2. Structure of the focal plane of the SH52: operating bands and looking angles are shown, for each line.

The SH52 is equipped with an optical device named tetrachroid, allowing for the co-registered acquisition of four bands: red, green, blue and near-infrared. The camera has two such devices so both the nadir and backward view perform co-registered acquisition of the four bands. The 12 channels acquired by SH52 can be combined in various ways; it is possible to form two stereoscopic colour images, for instance; it is also feasible to form two stereoscopic and co-registered colour infra-red (CIR) images, which are useful in forestry studies.

The other second-generation sensor head, SH51, is simpler and equipped with just one tetrachroid. The nadir lines have the same structure as in the SH52, while the forward and backward views have only one panchromatic line.

The new heads, compared with the first generation one, named SH40, have a considerably increased sensitivity, thus allowing shorter integration time. This has significant consequences: lower image noise level; better readability of the images in shadowed regions; extended operating window, daily and yearly; capability of acquiring images with a GSD below the 10 cm level (Tempelmann and Hinsken, 2007).

Finally the internal camera geometry is closer to the nominal model and more stable, due to technological improvements of the filters which are placed in front of the CCD lines and of the beamsplitter. In the SH40 the above-listed components produced image local deformations which could be up to 20 microns and were difficult to model. In the SH50 these deformations are kept below 1 micron, allowing for the adoption of a simpler camera mathematical model, allowing for very good geometric accuracy without performing any kind of camera self-calibration (Casella et al., 2008).

2.2 Operating ADS40 without ground based GPS support

Three-line sensors are based on GPS/IMU technologies for the reconstruction of the acquired images. However, the coverage of GNSS reference stations cannot always be guaranteed in all the mission areas (i.e. Third World countries or areas involved in a natural disaster). In these cases the Precise Point Positioning (PPP) technique can supply a sufficient accuracy in the determination of position using only the GNSS receiver mounted on the airplane.

PPP is a technique that allows improvement of the accuracy level of the traditional point positioning survey, through the use of precise orbit and clock data. Several organizations, such as IGS (International GNSS Service) or JPL (Jet Propulsion Laboratory), provide this information; the delay of this data is variable from a few hours (IGS Ultra-rapid product - 3hours) to some days (IGS Final product - 13 days). For disaster management purposes, only the former are feasible.

Several examples can be found in literature of the use of PPP technique for airborne positioning. Leica conducted some tests on this topic (Sacks and Tempelmann, 2008) to understand the obtainable accuracy. They analyzed the blocks acquired, at three different flying heights (500 m, 1000 m and 2000 m) above the Romanshorn test site. Two configurations were tested: the first has a small set of ground control points while the second one was without GCPs. In this second case, which is more interesting for rapid response mapping, the final accuracy achieved was sufficient for such purposes. Accuracy figures were evaluated by means of independent check points and are around 40 cm for x and y; between 5 and 10 cm for z; results are almost independent from flying height, especially for planimetric components.

We underline that the case studies presented in the paper are based on the more traditional GNSS relative positioning, requiring a receiver placed on a known point and acquiring for all the flight time: usually, a GNSS CORS. Nevertheless, knowing that ADS40's imagery can be orientated with an accuracy that is abundantly sufficient for rapid mapping, it greatly widens its usefulness and flexibility for disaster management.

3. THE THREE CONSIDERED DATASETS

Three case studies are considered to evaluate the benefits given by the ADS40 in disaster management; all the three datasets were acquired by the BLOM-CGR Company, located in Parma, Italy. The Company is equipped with several aerial cameras, analogue and digital, including two second-generation ADS40 cameras; it has a fleet of 9 aircrafts including a pressurized Lear Jet 25C (Figure 3), which can operate at high flying altitudes and allows for quickly reaching the areas to be surveyed.

Figure 3. The Lear Jet 25C operated by BLOM-CGR.

Block name	Average flying height [m]	GSD [cm]	Block size [Km^2]
L'Aquila	2500	25	572
Emilia	6800	68	5000
Pavia	2000	20	67

Table 1. Essential parameters of the considered blocks.

Table 1 summarizes the most essential parameters of the blocks considered. The *L'Aquila* dataset has been inserted into the paper because it refers to a real disaster management situation. The *Emilia* block covers a large region: accuracy assessment is performed, even though with a limited number of check points, and productivity considerations are carried out. The *Pavia* dataset was acquired above a photogrammetric test site and a rigorous geometric accuracy assessment of direct georefe-rencing is performed.

3.1 The *L'Aquila* dataset

L'Aquila is the capital of Abruzzo, a region situated in central Italy. On 6th April 2009, at 3:32 local time, an earthquake of 5.8 on the Richter scale was registered. The epicentre was near L'Aquila, which, together with surrounding villages, suffered most damage. Three-hundred and seven people died, making this the deadliest earthquake that has hit Italy in the last 30 years.
A few hours after the earthquake, BLOM-CGR started the operations in order to acquire a photogrammetric coverage above L'Aquila and the surrounding area. As examples of the damages caused by the earthquake, some images of two churches will be shown.

Figure 4. Detail of the old town of L'Aquila - Chiesa delle Anime Sante, Piazza Duomo.

Figure 5. The Chiesa delle Anime Sante dome after the earthquake.

Figure 6. Detail of the old town of L'Aquila - Chiesa di Santa Maria a Paganica, Piazza Santa Maria a Paganica.

Figure 7. The Chiesa di Santa Maria a Paganica nave after the earthquake.

Figure 4 clearly shows the damage suffered by the Chiesa delle Anime Sante dome; Figure 5 shows the same building taken some days later by an amateur photographer.
Another example is reported in Figure 6 and Figure 7 where the damage suffered by the Chiesa di Santa Maria a Paganica is shown; the whole nave of the church has collapsed after the earthquake.
Finally, an example is shown in Figure 8 of a rural building collapsed in a suburb of the city.

Figure 8. Detail of a suburban area of L’Aquila.

Concerning productivity and response time, the area surrounding L’Aquila was subdivided into three parts which were acquired on April the 6th, 7th and 8th. Image processing was performed in two steps, respectively producing quick orthophotos having ground resolutions of 1 m and 0.25 m. The examples shown here are cropped from the 0.25 m images. Within the evening of April the 9th, all the quick orthophotos were delivered: the total area surveyed is 572 square kilometres wide.

When *quick orthophotos* are produced, no image-mosaicing is performed between strips and as many orthos are produced as the acquired strips. The orthos were orientated by means of direct georeferencing: the exterior orientation parameters coming from the GPS/IMU system were used without any refinement; no ground control points (GCPs) nor tie points (TPs) were used. The orthoprojection was performed using a nation-wide DTM owned by the Company itself.

3.2 The *Emilia* case study

Since 1988, the BLOM-CGR (formerly CGR) Company has regularly acquired, every three years, images of the whole Italian territory. The name of this project is TerraItaly. The first flights were performed with analogue cameras, while more recently the ADS40 has been used. The average relative flying height of the project is 6000 m, corresponding to a ground resolution of 60 cm.

The TerraItaly flying configuration appears well suited for disaster management, when the hit territory is region-sized, therefore it was decided to include the *Emilia* block in the paper, which we had from BLOM-CGR for other previous research tasks.

The *Emilia* block was acquired in July 2008 above the western part of Emilia. The flight is constituted by eight East-West strips that embrace an area larger than 5000 km^2: each strip is approximately 120 km long. The territory imaged in the dataset is varied and contains flat areas, mountains, the sea, so it is very challenging for data processing.

The whole block was acquired in roughly two hours. Examining the files containing the exterior orientation parameters, which are also associated with a time tag, the productivity has been quantified. Considering the whole time spent for the core part of the block (excluding the approaching and return flights and the initialization manoeuvres, if needed), the time dedicated to image acquisition is 65% and flight turns take 35%.

Assuming the *Emilia* block configuration, productivity is 3100 square kilometres per hour. As the Lear Jet plane carrying the camera has four hours of autonomous flight, it is possible to survey at least 6000 square kilometres per flight, if the airport is not too far. According to the BLOM-CGR people’s experiences, emergency data processing for a similar amount of data is organized as follows: one unit performs trajectory calculation, requiring 2-4 hours; another unit performs in parallel the data download, requiring almost the same time. The production of quick orthophotos, which are the most typical output of emergency mapping, requires a longer time and can be performed only if a sufficient DTM is already available.

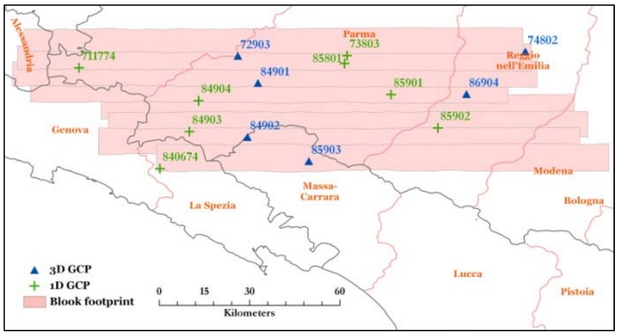

Figure 9. Outline of the *Emilia* block: the eight strips are shown, together with full CKPs (blue triangles) and pure altimetric ones (green crosses).

As Figure 9 shows, there are few check points available, those used by the Company in industrial production. This is not the case with the *Pavia* block, acquired above a special test site, in which a lot of very reliable points are available.

3.3 The *Pavia* dataset

In mid March 2008 a test flight was performed by the CGR company with a Casa 212 plane equipped with a second-generation Leica ADS40 camera with an SH52 sensor head. Three sub-blocks were acquired at the 800 m, 2000 m and 6000 m flying heights.

The 2000 m block was depicted for proper assessment of geometric issues and is constituted by four East-West strips and a cross one. Two of the former have the same flight path, but are flown in opposite directions (see Figure 10). GSD value is approximately 20 cm.

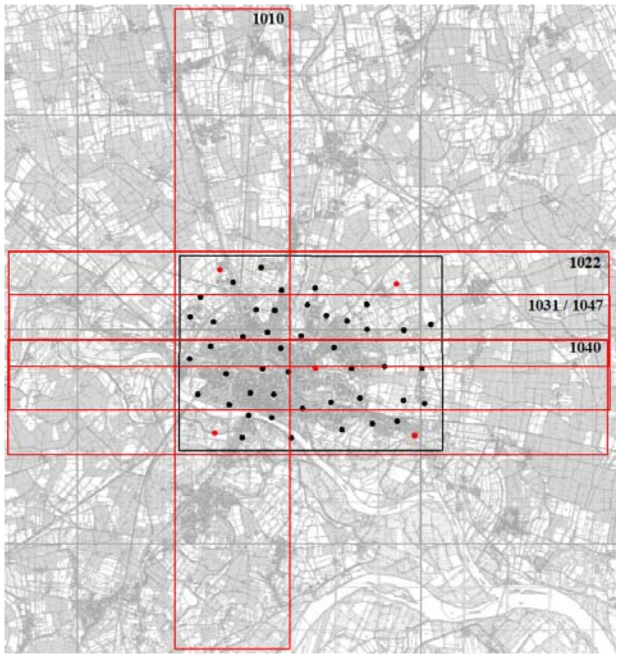

Figure 10. Outline of the 2000 m flying height block. The distribution of the control points is also shown; the black dots are used for DG assessment.

Forty check points are available, constituted by white squares painted on the ground, 60 cm sized. They were very accurately measured, see Section 4.

4. THE PAVIA TEST SITE

The Pavia Test Site was established by the Geomatics Laboratory, University of Pavia, Italy (Galetto et al., 2004). It has many relevant features which have been developed over the last 10 years, according to the needs of the ongoing research projects. There are features devoted to photogrammetric studies: 186 artificial control points (AGCPs), represented by white squares having a size of 35 cm painted on the pavement, and 56 natural control points (NGCPs).
Also, there are 120 larger artificial markers (BAGCPs) having a size of 60 cm, created in order to support ADS40 experiments. Fifty of these BAGCPs were added in 2003 and are used in the present paper, while the remaining 70 were added later.
All the GCPs have been measured with GPS in the fast static mode, using three fixed receivers, set up on vertices of Pavia's GPS network. The relative redundancy of the adjustment is therefore three, and the precision of the adjusted coordinates is very good: the average standard deviation is 3 mm for x and y and 7 for z. Unfortunately, the GPS measurement of the last 70 BAGCPs is still ongoing, therefore only the first 50 BAGCPs are considered in the paper.
The AGCPs, the NGCPs and the first 50 BAGCPs homogeneously cover the whole test-site, which is 6 x 4.5 km wide. The other 70 BAGCPs cover a larger area.
The distribution of the BAGCPs used in the present paper, the initial 50, is shown in Figure 10, projected on the background of the 1:10000 raster map of Pavia.

5. GEOEMTRIC ACCURACY ASSESSMENT OF DIRECT GEOREFERENCING FOR THE *EMILIA* AND *PAVIA* DATASETS

Only direct georeferencing is assessed, as the paper is concerned with rapid mapping.
For the sake of clarity, we remind the reader that direct georeferencing implies the *direct* use of the exterior orientation parameters coming from the GPS/IMU system, without any refinement; no ground control points (GCPs) nor tie points (TPs) are used.
Data processing was performed with the commercial software supplied by Leica: GPro 3.3 and Orima 9.1. This is the same configuration used by the BLOM-CGR company which supplied the data.
The assessment procedure is summarized: check points (CKPs) are inserted into the bundle-block adjustment as tie points, so that their object-space coordinates are determined within the adjustment. These object coordinates are then compared with those measured by GPS. We can say that DG has been performed because aerial triangulation was run assigning very high constraints on the given trajectory values.
Three statistical figures are considered: the mean, the standard deviation and the root mean square error. Here the formulas are outlined, for one of the three considered components, x, y and z. For the *i*-th CKP, $\tilde{x}_i$ is the value measured by photogrammetric methods; $\bar{x}_i$ is the true value, given by GPS. The difference is formed $\delta_i = \tilde{x}_i - \bar{x}_i$ and the following statistical figures are calculated

$$\text{mean} = m = \frac{1}{n}\sum_{i=1}^{n}\delta_i \quad \text{std} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\delta_i - m\right)^2} \quad \text{rmse} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\delta_i^2}$$

It may seem pedantic, but often, in papers, the exact meaning of the figures shown is uncertain.

5.1 Assessment of the *Emilia* dataset

The block, constituted by 8 East-West strips, was acquired for industrial purposes and not for science. There is a limited number of check points and their accuracy is not very high, but sufficient. Nevertheless there are 14 CKPs, 6 known in all components and 8 only in z. Their distribution is shown in Figure 9. Image coordinate measurements of CKPs were manually performed in stereo mode at BLOM-CGR.
Table 2 shows results for both CKP sets: for the 6 full control points, the RMSEs are, in GSD units, respectively 0.8, 1.5 and 1.3 for the x, y and z components; for the 8 altimetric ones, the RMSE is, for only z, 0.7.

Set	# CKP	Comp	mean [m]	std [m]	rmse [m]
DG 3D CKP	6	x	-0.033	0.469	0.470
		y	-0.845	0.249	0.881
		z	0.612	0.508	0.795
DG Z CKP	8	x	-	-	-
		y	-	-	-
		z	0.302	0.276	0.409

Table 2. Geometric accuracy assessment of the *Emilia* dataset.

The worst result is 1.5, in GSD units; we underline that the available CKPs only have a sufficient quality: performing other elaborations, not documented here, we established that they don't contain blunders, but, at the same time, they are rather noisy thus giving significant contribution to the noise figures reported in Table 2.

5.2 Assessment of the *Pavia* dataset

The block is constituted by 5 strips; among the 1031/1047 ones (Figure 6), having the same footprint but flown in opposite directions, only the 1031 was considered.
As described in Section 4, 40 signalized check points are available for accuracy assessment. The image coordinate measurements of these points were manually performed in mono mode at the Geomatics Laboratory of the University of Pavia.
Table 3 shows geometric accuracy results: the RMSEs are, in GSD units, 0.65 in planimetry (X,Y) and 1.1 in altitude (Z).

Set	# CKP	Comp	mean [m]	std [m]	rmse [m]
DG	40	x	0.078	0.110	0.135
		y	-0.022	0.130	0.131
		z	0.107	0.192	0.220

Table 3. Geometric accuracy assessment of the *Pavia* dataset.

Geometric accuracy proves to be almost within pixel size, for all the components and this is a very good result for direct georeferencing.

6. CONCLUSION

The paper deals with the use of the Leica ADS40-SH52 camera for rapid mapping in disaster management. Only the direct georeferencing mode is considered. Three blocks are taken into

consideration; some examples and reflections are presented, concerning the productivity of the camera and its geometric accuracy. Moreover, a short discussion about PPP technique for airborne positioning is also given.
The *L'Aquila* block is presented because it was acquired in a real emergency situation and the delivery time of the fast orthophotos produced can be documented.
The *Emilia* block is an example of a large survey. The acquisition rate is 3000 square kilometres per hour with 60 cm GSD; geometric accuracy is below 1.5 GSD, for all the components, which is sufficient for rapid mapping purposes.
Finally, the *Pavia* block allows for rigorous and reliable assessment and presents accuracy values which are not greater than 1 GSD.
The Leica ADS40 camera has several strengths for disaster management: it acquires 5 radiometric channels at a time and three stereoscopic images; it is highly productive, with respect to the GSD; has a good geometric accuracy even in the direct georeferencing mode.

7. ACKNOWLEDGMENT

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