Leica ADS40 imagery for disaster management

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Abstract
Every year environmental disasters such as storms, floods and earthquakes cause thousands of deaths and a great deal of damage around the world. The scientific community is involved in the endeavour of monitoring environmental problems, preventing disasters 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.
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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 (EOPs) measured by GNSS/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 metres and the corresponding image footprint can be as large as 10 km, across-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 GNSS/IMU (Leica IPAS20) devices which measure EOPs directly. Image acquisition by aerial large-format digital cameras can be very quick when direct georeferencing (DG) is performed: thanks to the direct measurement of the EOPs, the image orientation phase only takes a few hours after landing. Direct georeferencing sometimes shows accuracy and reliability problems, but the second and third generations of the Leica ADS camera perform very well and present accuracy figures not exceeding the pixel size.
Several examples of the use of ADS40 imagery for disaster management can be found in world literature. Concerning Italy, an ADS40 camera, owned by Blom CGR (Parma), was used to acquire several images of L'Aquila area immediately after the earthquake that hit the city in April 2009: this is one on the case studies considered in the paper.
A more recent example refers to an oil spill problem which hit the Lambro river in Northern Italy: in the early morning of 23rd February 2010, 10 million litres of gas oil, situated in

Villasanta, leaked from their tanks into the Lambro river. On that occasion a Casa airplane, owned by Blom CGR, flew above the area, equipped with ADS40-SH52 camera and a multispectral sensor MIVIS. The camera acquired four strips of 80 km in length; the GSD (Ground Sampling Distance) was 15 cm.
The paper focuses on fast orientation methodologies for the Leica ADS40-SH52 camera, therefore the direct georeferencing methodology is uniquely considered. Mainly, geometric accuracy and camera productivity are investigated.

The three considered case studies

Three case studies are considered to evaluate the ADS40 camera in disaster management, all acquired by Blom CGR, located in Parma, Italy. The Company is equipped with several aerial cameras, analogue and digital, including two second-generation ADS40 cameras and two Vexcel UltraCam XP ones; it has a fleet of 9 aircrafts including a pressurized Lear Jet 25C (Fig. 1), which can operate very quickly, at long range and at high flying altitudes.

Figure 1 - The Lear Jet 25C operated by Blom CGR.

The case studies are named *L'Aquila, Emilia* and *Pavia.* The first one was inserted into the paper because it refers to a real disaster management situation. The *Emilia* block covers a large area and illustrates which kind of surveying can be performed in region-sized disasters: accuracy assessment is performed, even though with a limited number of check points, and productivity considerations are carried out. Finally, the *Pavia* dataset was acquired above a photogrammetric test site and allowed for a rigorous geometric accuracy assessment. Table n 1 below summarizes the main geometric parameters of the acquired blocks.

Table 1 - Essential parameters of the considered blocks.

Site	Average flying height [m]	GSD [cm]	#Strips	Block size [Km^2]
L'Aquila	2500	25	-	572
Emilia	6800	68	8	5000
Pavia	2000	20	3	67

The L'Aquila dataset

On 6th April 2009, in the Abruzzo Region, 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, operating in the frame of the Telaer Consortium, started the operations in order to acquire a photogrammetric coverage above L'Aquila and the surrounding area. More precisely, the entire area was acquired with three sensors: the Leica ADS40-SH52 camera (some images are shown in this paper), the Optech ALTM Gemini lidar sensor and a Pictometry® device for oblique image capture. As examples of the damages caused by the earthquake, some images of the city centre and of the surrounding areas are shown (Fig. 2).

Figure 2 - From left to right: details of the damages suffered by a church and by two suburban areas

The Emilia dataset
Since 1988, the Blom CGR has regularly acquired images of the whole Italian territory, inside TerraItaly™ project. 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 6800 m, corresponding to a GSD of 68 cm; the image footprint is 8000 m, across-track.
The TerraItaly™ flying configuration appears well suited for disaster management. The *Emilia* block was acquired in July 2008 above the western part of Emilia. The flight is constituted by eight East-West strips, embracing 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 and the sea, so it is very challenging for data processing.

The Pavia dataset
In mid March 2008 a test flight was performed by the Blom CGR 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. GSD value is approximately 20 cm.
Forty check points are available, constituted by white squares painted on the ground, 60 cm in size. They were very accurately measured with redundant static GPS.

Geometric accuracy assessment of direct georeferencing
Geometric accuracy of direct georeferencing is analyzed first, in order to preliminarily check whether the paper's assumption is correct: with second and third generations of

the Leica ADS camera, direct georeferencing is sufficient for rapid response mapping. Two datasets are only considered, the *Emilia* and *Pavia* blocks, for which ground control information is available.

The Emilia dataset

The block was acquired for industrial purposes and not for science. There are 14 CKPs, 6 known in x, y and z, while the remaining 8 only in z; their coordinates are known with a sufficient accuracy.

Image coordinate measurements of CKPs were manually performed in stereo mode at Blom CGR. Table n 2 shows results for both CKP sets: for the 6 full control points, the RMSEs are, in GSD units, respectively 0.7, 1.3 and 1.1 for the x, y and z components; for the 8 altimetric ones, the RMSE is 0.6 for z.

The worst result is 1.3, in GSD units; we recall again that the available CKPs only have a sufficient quality: they don't contain blunders, but are rather noisy, as we stated with further analysis, not documented here. Therefore, random noise contained in the control coordinates presumably gives a significant contribution to the noise figures reported.

Table 2 - Geometric accuracy assessment of the Emilia dataset.

Set	# CKP	Comp	x	y	z
3D CKP	6	Mean [m / GSD units]	-0.033 / 0.1	-0.845 / 1.2	0.612 / 0.9
		STD [m / GSD units]	0.469 / 0.7	0.249 / 0.4	0.508 / 0.7
		RMSE [m / GSD units]	0.470 / 0.7	0.881 / 1.3	0.795 / 1.1
Z CKP	8	Mean [m / GSD units]	-	-	0.302 / 0.4
		STD [m / GSD units]	-	-	0.276 / 0.4
		RMSE [m / GSD units]	-	-	0.409 / 0.6

The Pavia dataset

The block considered here is constituted by only 3 parallel strips, East-West oriented. Forty signalized check points were used 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 n 3 shows geometric accuracy results: the RMSEs are, in GSD units, 0.7 in planimetry (x, y) and 1.1 in altitude (z).

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

Table 3 - Geometric accuracy assessment of the Pavia dataset.

Set	# CKP	Comp	x	y	z
DG	40	Mean [m / GSD units]	0.078 / 0.4	-0.022 / 0.1	0.107 / 0.5
		STD [m / GSD units]	0.110 / 0.6	0.130 / 0.7	0.192 / 1.0
		RMSE [m / GSD units]	0.135 / 0.7	0.131 / 0.7	0.220 / 1.1

Productivity and promptness issues

In the present section, productivity and response time issues are treated, according to the direct experiences of the Blom CGR people. The *quick orthophoto* expression is used in the following, which was introduced by the authors in order to give a name to a particular product which was specifically developed for rapid mapping purposes. The orthophoto production chain can be very quickly summarized as follows: image acquisition, image orientation, DTM production (only if there isn't one, already), orthoprojection of the single images, image mosaicing and colour balancing. The last two tasks require the definition of seam lines, which is usually performed in a semi-automatic way, needing user supervision and editing. Image mosaicing and colour balancing are particularly demanding when frame imagery is acquired and a great number of parts are involved; line cameras have a great advantage because no stitching nor balancing is needed along-track, but only across-track. Quick orthos represent a further step: the single orthoprojected strips are kept separated and delivered to the final user. He has the very minor inconvenience of jumping from one image to the next one, which is over-exceeded by the advantage of much faster delivery time. Furthermore, the quick orthos mentioned here were produced by means of direct georeferencing: the exterior orientation parameters coming from the GNSS/IMU system were used without any refinement; no ground control points (GCPs) nor tie points (TPs) were used. Finally, the orthoprojection was performed using an existing, nation-wide DTM, owned by the Company itself.

The L'Aquila dataset

L'Aquila block was subdivided into three parts which were acquired on April 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. By the evening of April 9th, all the quick orthophotos were delivered: the total area surveyed is 572 square kilometres wide.

The Emilia dataset

The whole block was acquired in roughly two hours. By 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 one hour for each hour of acquisition. The production of quick orthophotos, which are the most typical output of emergency mapping, requires approximately ½ hour for a strip

of 10 km, corresponding to an area of 82 square kilometres, provided that a DTM of the area is available. The time reported refers to the production of four independent orthoprojected components, corresponding to red, green, blue and NIR channels, so that all the useful images can be quickly generated in a second time: PAN, RGB and CIR.
Since the *Emilia* block is formed by strips 120 km long, it takes about 6 hours to obtain the orthoprojection of an entire strip. The production of several strips does not necessarily imply a linear increase in processing time, since the Leica software is able to perform parallel processing, if there is a dedicated hardware platform; this means that as many strips as the number of the nodes (*nodes* are the CPUs belonging to the special hardware used for parallel computing) in the system can be computed simultaneously. Blom CGR has a 32-node system, so they are capable of processing in parallel a very large block. In conclusion, it can be stated that, in emergency conditions, the quick orthophotos for the *Emilia* block configuration may be carried out the same day, provided that a sufficient DTM is available.

Conclusions
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.
The *L'Aquila* block is presented because it was acquired in a real emergency situation and the delivery time of the fast orthophotos produced could be documented. The *Emilia* block is an example of a large survey. The acquisition rate is 3000 square kilometres per hour with 68 cm GSD; geometric accuracy is below 1.3 GSD, for all the components, which is sufficient for rapid mapping purposes. The block was acquired for industrial purposes and there is a limited number of check points. Therefore our results can't be as reliable as we would like, but they are confirmed by the *Pavia* block.
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 is highly productive, with respect to the GSD; has a good geometric accuracy even in the direct georeferencing mode.

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