

# INITIAL EVALUATION OF THE SECOND-GENERATION LEICA ADS40 CAMERA

V. Casella<sup>a</sup>, M. Franzini<sup>a</sup>, G. Banchini<sup>b</sup>, G. Gentili<sup>b</sup>

<sup>a</sup>University of Pavia, Department of Building and Territorial Engineering, Via Ferrata, 1, I - 27100 Pavia, Italy  
(vittorio.casella, marica.franzini)@unipv.it

<sup>b</sup>Compagnia Generale Ripresearee, Via Cremonese, 35A, I - 43100 Parma, Italy  
(gbanchini, ggentili)@cgrit.it

Commission I, WG I/4

**KEY WORDS:** Photogrammetry, Three-line, Pushbroom, Camera, Triangulation, Calibration, Accuracy

## ABSTRACT:

In late 2006, Leica Geosystems, Heerbrugg Switzerland, announced the availability of the second-generation ADS40 camera, having several new and improved features.

The Italian company Compagnia Generale Ripresearee (CGR), Parma Italy, a subsidiary of Blom ASA, Norway decided to upgrade both its ADS40 cameras to the second generation. The first modified one came back from the Leica factory in March 2008 and a previously planned test flight was soon performed over the Pavia test site. Noticeably, data from the same test site was acquired several other times: in 2004, jointly by a first generation Leica ADS40 and a Leica RC30, at different altitudes; in 2003 by a RC30 at various flying heights.

The newly acquired dataset is constituted by three blocks at the flying heights 800, 2000 and 6000 metres. The paper is an early contribution to the validation of the second-generation ADS40 camera. First of all, it focuses on geometric accuracy of the 2000 m block, showing that direct georeferencing accuracy is within 1 GSD; when aerial triangulation is performed, without camera self calibration, accuracy is below half of the pixel, in all the components; when IMU misalignment re-estimation is additionally performed, RMSE values are between 0.18 and 0.31 of the GSD.

The paper also contains some visual checks of the degree of detail of the imagery acquired at 800 m, having a GSD of 8 cm: they are compared with some previously acquired Leica RC30 imagery, having a 7 cm GSD. Some shots of the recently made Siemens star are also shown.

## 1. INTRODUCTION

### 1.1 Background

The photogrammetric processing of imagery produced by airborne line cameras is a challenging research area. The complete definition of topics like camera models, trajectory models and camera calibration still need investigating and case studies made.

The first-generation Leica ADS40 camera has already been studied through two datasets acquired over Pavia, Italy, and Vaihingen, Stuttgart, Germany.

Concerning the Italian dataset, there were activities wholly developed at the University of Pavia (Casella et al., 2007b; Casella et al., 2007c) and also some joint tests carried out at the University of Pavia and at the IGP, ETH Zurich (Casella et al., 2007a; Kocaman et al., 2007a; Kocaman et al., 2007b). Joint papers are based on the use of exactly the same dataset (in terms of image coordinates, weights of observations, the distinction between control and check points and their object coordinates) and of different orientation algorithms and programs. Interestingly, the results of the two Groups are equivalent and show the same behaviour: very briefly, there are strong biases in the object coordinates of check points in direct georeferencing (DG); it is impossible to reach sub-pixel accuracy with mere aerial triangulation; when camera self-calibration is performed, accuracy is increased to small fractions (1/4 to 1/6) of the pixel. Further details can be found in the referenced papers and in Section 4.

The Vaihingen ADS40 dataset has been repeatedly used. Cramer (2006) and Kocaman et al. (2006) report individual tests, but the dataset has also been used for the EuroSDR project framework "Digital Camera Calibration", reported in Cramer (2007).

The second-generation ADS40 camera is described by Tempelmann and Hinsken (2007): they illustrate the new camera features and the related expected benefits. A further paper from Saks and Tempelmann (2008) also shows some interesting results regarding geometric accuracy. The experiments described mainly concern the use of the precise point positioning (PPP) GPS methodology, instead of the usual static, relative positioning, but, nevertheless, the presented results constitute a first assessment of the accuracy potential of the recently introduced camera.

### 1.2 Motivation, goal and structure of the paper

In late 2006, Leica Geosystems, Heerbrugg Switzerland, announced the availability of the second-generation ADS40 camera, having several new and improved features: the novel tetrachroid device allows for the acquisition of four co-registered channels, red, green, blue and near-infrared; an increased camera sensitivity resulting in reduced noise level, shorter integration time and, consequently, higher ground resolution and/or increased productivity. Further details about the camera can be found in Section 3.

The Italian company Compagnia Generale Ripresearee (CGR), Parma Italy, a subsidiary of Blom ASA, Norway, owned two ADS40 cameras (they bought the first one in 2004, which was the first ADS40 in Europe) and decided to upgrade both to the second generation. The first upgraded one came back from the Leica factory in March 2008 and a previously planned test flight was soon performed over the Pavia test site (PATSI).

The present paper concerns some initial experiments performed on the newly acquired dataset and focuses on four main questions.

- How accurate is direct georeferencing (DG)?

- What is the attainable accuracy when self-calibration is not performed? In other words: is camera self-calibration still necessary to reach high accuracy levels?
- Is it possible to acquire images having a native ground sampling distance (GSD) below 10 cm, in both directions?
- Is the improved radiometric quality easily detectable?

Noticeably, the same test site was acquired in August 2004 by a plane operated also by the CGR company, equipped with two cameras: a first-generation Leica ADS40 camera and a Leica RC30, so that it is possible to compare geometric accuracy, radiometric quality and the level of detail of three different cameras working on the same field.

Section 2 illustrates the test site and the dataset used, while Section 3 illustrates some features of the second-generation Leica ADS40 camera. Section 4 summarizes the main test results concerning the dataset acquired in 2004 with a first-generation ADS40. Section 5 illustrates geometric accuracy results for the new camera, assessed by means of the newly acquired dataset. Finally Section 6 presents some views of the acquired images, in order to check the level of detail of those belonging to the 800 m block and to visually check their radiometric quality.

## 2. TEST SITE AND DATASETS

### 2.1 Pavia test site

The Pavia test site has been established by the Geomatics Laboratory, University of Pavia, Italy (Galetto et al., 2004). A number of signalized and natural GCPs have been added to the site.

There are 186 artificial control points (AGCPs) represented by white squares, having a size of 35cm, 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. 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 PATSI, which is 6 x 4.5 km wide. The other 70 BAGCPs cover a larger area. The distribution of the BAGCPs used in the paper is shown in Figure 1, projected on the background of the 1:10000 raster map of Pavia.

The latest addition to PATSI is a Siemens star having a 5.4 m diameter, which was placed on the roof of the building hosting the Geomatics Laboratory during the acquisition of the recent ADS40 dataset: it is shown in Figure 4.

### 2.2 The recent ADS40 flight

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 800 m block is constituted by two orthogonal strips and its aim is to check the possibility of acquiring images with very high ground resolution: in this case GSD is around 8 cm.

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. This block is also meant for comparison with a similar one, which in 2004 was acquired over the same area. GSD value is approximately 20 cm.

Finally, the 6000 m flying height block is constituted by two East-West strips plus a cross one. This altitude is particularly interesting for the CGR company, as it is used for a nation-wide orthophoto project named Terraltaly™.

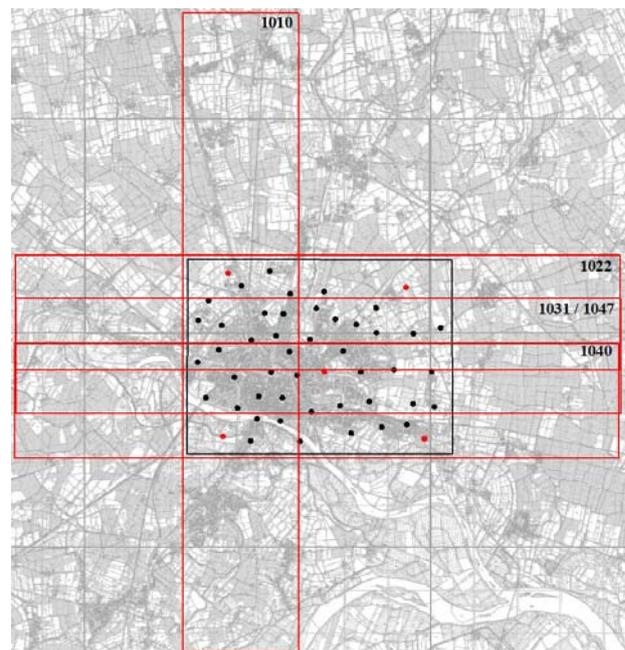


Figure 1. Distribution of the 45 control points used; the red ones are used as GCPs in aerial triangulation; the outline of the 2000 m flying height block is also shown. The strip apparently having two names was flown twice, in opposite directions.

### 2.3 Previous datasets

In August 2004 a test flight was performed over PATSI by the CGR company. The plane used was equipped with two cameras: a first-generation Leica ADS40 camera and a Leica RC30. Three blocks were acquired, at three different flight altitudes, 2000, 4000, and 6000 metres. For each sub-block, the ADS40 imagery and the RC30 are available. Corresponding GSD values are, for both the cameras, 20 cm, 40 cm and 60 cm, approximately (Casella et al., 2007b).

Within the frame of a research project on IMU-aided photogrammetry, a large dataset was acquired over PATSI in 2003. It includes, among others, two blocks imaged with a Leica RC30 camera at the 750 m flying height, whose corresponding digitized images have a 7 cm GSD. They are used in the paper for comparison with the newly acquired 800 m ADS40 images (Galetto et al., 2004).

## 3. THE SECOND-GENERATION ADS40 CAMERA

The new and improved features characterizing the second-generation camera are contained in the sensor head, so that

Leica speaks about a unique camera which can be equipped with three different heads: the old one, named SH40, and the new ones, SH51 and SH52. This makes the upgrade of an existing camera to the second generation feasible. The present section focuses on a quick summary of the features which are relevant for the topics of the paper.

A significant technological improvement is represented by the so-named **tetrachroid**, a new, patented, device allowing for the co-registered acquisition of four bands: red, green, blue and near-infrared.

The composition and the inclination of the views have been redefined, as illustrated by Figure 2, concerning SH52, which is equipped with two tetrachroids. At the top is shown the forward view, having a 27° looking-angle (instead of 28°, as it is in the SH40), consisting of only one panchromatic line. The nadir view consists of four multispectral, co-registered lines, corresponding to the red, green, blue and near-infrared channels, and of two staggered panchromatic lines, having a 2° inclination. Finally, the backward view has the usual four co-registered channels, characterized by a looking angle of 16° (instead of the 14° of the first generation) plus a tilted panchromatic line.

The 12 channels acquired by SH52 can be combined in various ways; it is possible to form two stereoscopic colour images, for instance, which was not possible for SH40; it is also feasible to form two stereoscopic and co-registered colour infra-red (CIR) images, which are useful in forestry studies.

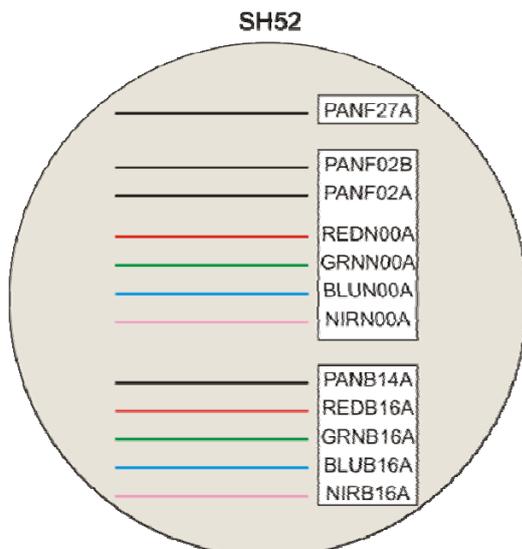


Figure 2. Structure of the focal plane of the SH52: operating bands and looking angles are shown, for each line.

The SH51 head 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 have a considerably increased **sensitivity**, thus allowing shorter integration. 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 SH40 the above-listed components produced image local deformations which could be up to 20 microns and were difficult to model. In SH50 these deformations are kept below 1 micron, allowing for the adoption of a simpler camera mathematical model.

#### 4. RESULTS FROM PREVIOUS EXPERIMENTS

Selected results from previous experiments and papers are reported here, in order to facilitate the comparison.

The ADS40 dataset acquired in 2004 (Casella 2007a) contains three blocks, characterized by the flying heights 2000, 4000, 6000 meters. In the following, only the first block is considered, whose outline is shown by Figure 3, in order to compare its results with those derived from the analogous block belonging to the 2008 dataset.

The assessment was performed considering three main scenarios:

- **DG**, in which the exterior orientation parameters (EOPs) measured by the GPS/IMU are used directly;
- **BASIC**, where aerial triangulation is performed and EOPs coming from the GPS/IMU are inserted into the adjustment as observations, together with tie points and GCPs;
- **SELF**, in which camera self-calibration is performed, plus a datum transformation is estimated and the misalignments between camera and IMU are re-determined.

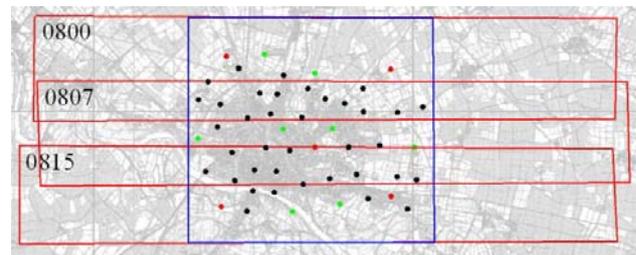


Figure 3. Structure of the 2000 m block of the 2004 dataset and distribution of control points

Two GCP configurations were considered, with 5 and 12 points. Nevertheless, in the following, the 5-GCP arrangement is only evaluated and results are shown in Table 1.

Set	GCPs/ CKPs	Comp.	Mean [m]	STD [m]	RMSE [m]
<b>DG</b>	0 / 46	<b>x</b>	0.015	0.119	0.120
		<b>y</b>	-0.007	0.093	0.093
		<b>z</b>	-0.558	0.319	0.643
<b>BASIC</b>	5 / 41	<b>x</b>	0.088	0.224	0.240
		<b>y</b>	0.016	0.265	0.265
		<b>z</b>	-0.361	0.145	0.389
<b>SELF</b>	5 / 41	<b>x</b>	0.024	0.052	0.057
		<b>y</b>	-0.008	0.036	0.037
		<b>z</b>	-0.029	0.084	0.089

Table 1. Assessment of the 2000 m flight of the 2004 dataset.

DG presents a strong bias in Z. The BASIC configuration, in which mere aerial triangulation is performed, has RMSE values all above the pixel size; considering all three blocks confirms (Casella, 2007b) that it is impossible to reach the usual photogrammetric accuracy level without performing camera

self-calibration, regardless of the GCP number. The SELF mode, in which self-calibration is performed, shows very good results and RMSEs are all below 1/3 of the pixel. Detailed comments can be found in the referenced literature.

## 5. GEOMETRIC ACCURACY ASSESSMENT FOR THE 2008 DATASET ACQUIRED WITH THE NEW SH52

### 5.1 Data preparation

Data processing was performed with the commercial software supplied by Leica: LPS 9.1, GPro 3.3 and Orima 9.1. This is the same configuration used by the CGR company which supplied the data. The above-listed, last-generation Leica programs present new interesting features such as the possibility of performing tie point extraction on the L0 images and of re-estimating IMU misalignments on a per-strip basis.

Eleven channels were acquired during the flight, including all the lines shown in Figure 2 with only the exception of PANF02B. Concerning the strips 1031/1047, having the same footprint but flown in opposite directions, only the 1031 was considered, until now.

CGR also provided the authors with camera calibration, constituted by the so-named CAM files, and the three misalignment angles between IMU and camera. Calibration was performed by Leica Geosystems using a test flight acquired in Switzerland. The dataset used for camera calibration and that used for the experiments reported in the paper are totally independent.

At present, only the 2000 m block has been considered for geometric accuracy evaluation. The image coordinate measurements of the signalized control points were manually performed in mono mode at the Geomatics Laboratory of the University of Pavia. Tie point extraction was automatically performed with the APM (Automatic Point Measurement) procedure of GPro, directly on the L0 images, thanks to the innovative capabilities of recent Leica programs.

Aerial triangulation was performed on the L0 version of the three panchromatic images and the following weights were used, for the various observations:

- image coordinates: 1/3 pixel (= 2.2 micron);
- object coordinates of GCPs: 1.5 cm for X,Y and 2 cm for Z;
- GPS/IMU measurements: 10 cm for X,Y and 20 cm for Z; 0.006<sup>g</sup> for  $\omega$ ,  $\phi$  and 0.009<sup>g</sup> for  $\kappa$ .

### 5.2 Test results

During the described experiments, four configurations were considered:

- **DG**, in which the exterior orientation parameters (EOPs) measured by the GPS/IMU are used directly;
- **AT**, where mere aerial triangulation is performed to improve EOP;
- **AT+MIS**, in which the bundle-block adjustment is extended in order to re-estimate the IMU misalignment (three angles) for the whole block;
- **AT+MIS-2**, in which IMU misalignment re-estimation is performed on a per-strip basis, so that a different misalignment triplet was determined for each strip; internal camera geometry is left unchanged.

Camera self calibration was not considered in this early investigation phase, also because results show that it is not necessary to reach top-quality accuracies. Nevertheless, in-flight camera calibration will be taken into account in further papers in order to determine the geometric accuracy potential of the second-generation ADS40 camera.

For the sake of clarity, 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. The DG scenario assessment was performed with aerial triangulation again, with very high constraints on the given trajectory values.

Set	GCPs/CKPs	Comp.	Mean [m]	STD [m]	RMSE [m]
DG	0 / 40	x	0.078	0.110	0.135
		y	-0.022	0.130	0.131
		z	0.107	0.192	0.220
AT	5 / 40	x	0.049	0.040	0.064
		y	-0.071	0.056	0.091
		z	-0.016	0.070	0.072
AT+MIS	5 / 40	x	0.040	0.035	0.053
		y	-0.041	0.057	0.070
		z	0.025	0.066	0.071
AT+MIS-2	5 / 40	x	0.003	0.036	0.036
		y	0.011	0.058	0.059
		z	0.024	0.057	0.062

Table 2. Assessment of the 2000 m flight of the 2008 dataset, acquired with SH52.

Table 2 and Figure 4 show results for the four considered scenarios. In direct georeferencing (DG) RMSEs are, in GSD units, 0.65 in planimetry (X,Y) and 1.1 in altitude (Z). When mere aerial triangulation is performed (AT), RMSEs are well below one half of the pixel. Re-estimating IMU misalignments on a per-block basis (AT+MIS) improves results. Performing a per-strip misalignment re-estimation significantly improves the performance once again. In the best considered configuration, AT+MIS-2, RMSEs range between 0.18 and 0.31 of the GSD. The average values are small, showing the absence of significant systematic effects; minimal exceptions are the Z component in DG, and the Y component in AT, the latter probably being due to slightly inconsistent IMU misalignments, as it disappears when the other scenarios are considered.

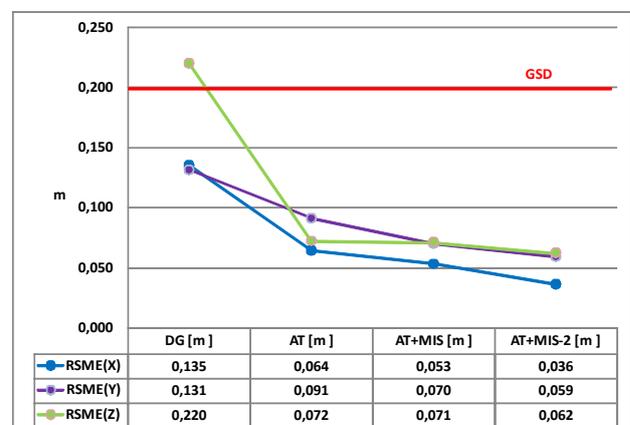


Figure 4. Graphical illustration of RMSE values 2000 m flight of the 2008 dataset, reported in Table 2 also.

The comparison between Table 2 and Table 1 shows that geometric accuracy of SH52, in the AT configuration, is comparable to that of SH40 with the SELF arrangement; when the best considered configurations are considered for both cameras, SH52 is better than SH40, even without performing self calibration.

## 6. GEOMETRIC RESOLUTION

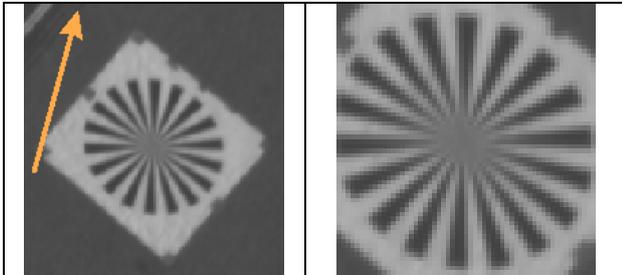


Figure 5. The Siemens star imaged from the 800 m flying height.

One of the most interesting new features of SH52 is the capability of acquiring images having GSD values as small as 5 cm. With ADS40, being a line camera, across-track ground resolution can be increased by flying at lower altitudes but, to obtain the same resolution along-track, it is necessary to have either very short integration time or very low flying speed.

(Saks and Tempelmann, 2008). In the case of the CGR test flight, the minimum safe configuration corresponded to a flying height of 800 m and a GSD of 8 cm and it is important to check the isotropy of such an high resolution.

In order to support such checks, a Siemens star having a diameter of 5.4 meters was placed on the roof of the building hosting the Geomatics Laboratory at the University of Pavia and imaged during the flights. It is shown in Figure 5: on the left flying direction is also indicated, while on the right a zoomed view is shown.

In further papers, rigorous assessment on the Siemens star will be performed, in terms of transfer contrast function, which was impossible within the present paper due to time constraints. However Figure 5 doesn't show any visibly detectable anisotropy in the level of detail.

Moreover, Figure 6 shows a comparison between ADS40-SH52 images and those produced by a Leica RC30, related to a typical test bed, the railway. In the upper row, three image patches are shown, extracted from the panchromatic L1 ADS40 imagery acquired at the 800 m flying height, having an 8 cm GSD. The three images are shown at the 1X, 2X and 4X zoom ratios, respectively, from left to right.

The lower row shows image patches from a Leica RC30 colour image, acquired in 2003 at the 750 m flying altitude and successively scanned with a Zeiss SCAI device with a 14 micron resolution; the resulting GSD is 7 cm.

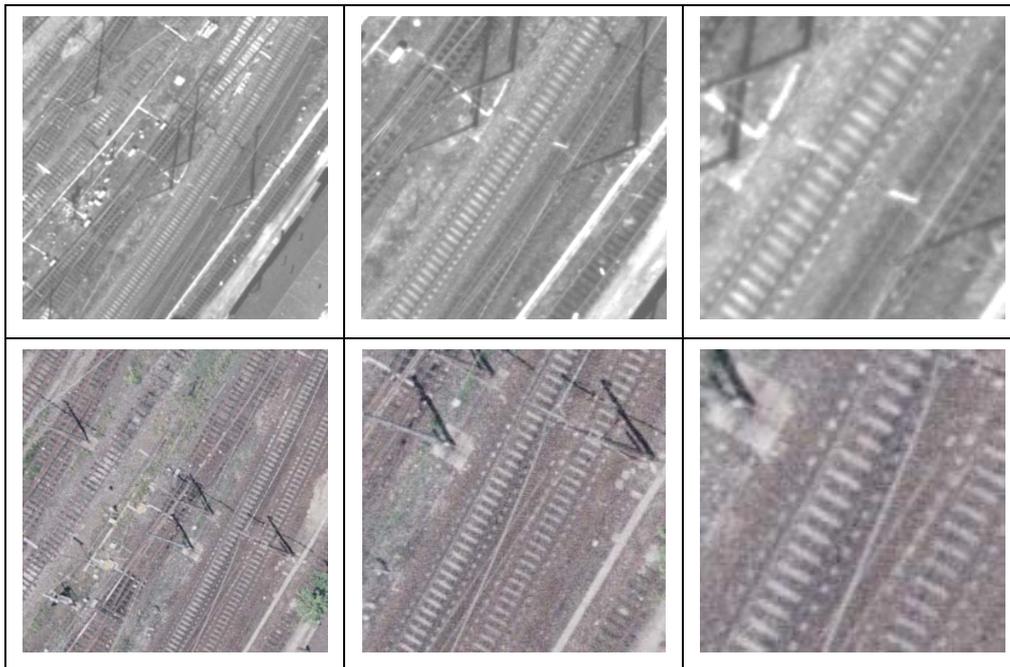


Figure 6. Comparison between ADS40-SH52 images having a 8 cm GSD (in the upper row) and RC30 ones, having a GSD of 7 cm (in the lower row)

Flying very low but not slow enough produces rectangular pixels, which can be squared by interpolation: but the so-obtained high resolution is not natively acquired.

The combination of the listed constraints prevented the first-generation SH40 from acquiring images with a GSD smaller than 15 cm, especially for colour channels. The new SH52 is capable of reaching even 5 cm, depending on the plane used

One may ask why panchromatic and colour images are compared, and the reason is simply that difficulties were met in producing ADS40 L1 colour images, for an unknown reason which still has to be investigated. However Figure 6 shows that ADS40 images are comparable or better, in terms of detail level, than the RC30 images, which have a nominal higher ground resolution.

## 7. CONCLUSIONS

A dataset acquired over the Pavia, Italy test site is analyzed in the paper, which was imaged with a second-generation Leica ADS40 camera, by the Italian company Compagnia Generale Ripreseaeree. The experiments performed mainly focus on geometric accuracy and in part on geometric resolution.

Different orientation scenarios are considered: direct georeferencing; aerial triangulation without camera self-calibration; aerial triangulation plus IMU misalignment re-estimation. Concerning the 2000 m block, direct georeferencing has an accuracy within 1 GSD; when aerial triangulation is performed, without camera self calibration, accuracy is below half of the pixel, in all the components; when IMU misalignment re-estimation is additionally performed, RMSE values are between 0.18 and 0.31 of the GSD. Geometric accuracy figures of direct georeferencing are compatible with the production requirements of several photogrammetric products.

Interestingly, results can be compared with others related to a first-generation ADS40 camera, obtained from the Pavia test site, once again. According to these recent and previous experiments, the new camera, with only aerial triangulation and IMU misalignment re-estimation, performs better than the older with camera self calibration.

The real geometric resolution of the images acquired at 800 m, having 8 cm GSD, is also visually checked by means of a Siemens star and by comparison with some previously acquired Leica RC30 imagery, having 7 cm GSD.

## ACKNOWLEDGMENT

The authors are pleased to thank two technicians of the Geomatics Laboratory of the University of Pavia, geom. Giuseppe Girone and geom. Paolo Marchese for performing some of the image coordinate measurements used in the experiments described.

Dr. Barbara Padova, a young researcher of the same Laboratory, is also thanked for performing some other measurements and for supporting the compilation of the paper elaborating graphics and performing some image analysis tasks.

## REFERENCES

Casella, V., Franzini, M., Kocaman, S., Gruen, A., 2007a. Triangulation and Self-calibration of the ADS40 Imagery: A Case Study over the Pavia Test Site. Proceedings of the 8th Conference on "Optical 3D Measurement Techniques", Zurich, Switzerland, 9-12 July, Vol. I, pp. 223-232.

Casella, V., Franzini, M., Padova, B., 2007b. Accuracy assessment of ADS40 imagery as a function of flying height and of aerial triangulation strategies. Proceedings of 5th MMT Symposium, Padova, Italy, 29-31 May (on CD-ROM).

Casella, V., Franzini, M., Padova, B., 2007c. Valutazione dell'accuratezza delle immagini ADS40 in funzione del modello di camera e della quota di volo. Proceedings of the 11th ASITA National Conference, Torino, Italy, 6-9 November.

Cramer, M., 2006. The ADS40 Vaihingen/Enz geometric performance test. *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 60, Issue 6, pp. 363-374.

Cramer, M., 2007. The EuroSDR Performance Test for Digital Aerial Camera Systems. Proceedings of the 51st Photogrammetric Week, Stuttgart, Germany, 3-7 September. pp.89-106.

Galetto R., Casella V., Franzini M., Spalla A., 2004. An Italian research project on direct photogrammetry. *Int. Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Istanbul, Turkey, Vol. 35, Part B3, Com. III, pp. 891-896.

Gruen, A., Zhang, L., 2003. Sensor Modeling for Aerial Triangulation with Three-Line-Scanner (TLS) Imagery. *Journal of Photogrammetrie, Fernerkundung, Geoinformation (PFG)*, 2/2003, pp. 85-98.

Hinsken, L., Miller, S., Tempelmann, U., Uebbing, R., Walker, S., 2002. Triangulation of LH Systems'ADS40 imagery using ORIMA GPS/IMU. *IAPRS*, Vol. XXXIV, Part 3A, Graz, Austria, 7 pages (on CD-ROM).

Kocaman S., Zhang L., Gruen A., 2006. Self-calibrating Triangulation of Airborne Linear Array CCD Cameras. EuroCOW 2006 International Calibration and Orientation Workshop, Castelldefels, Spain, 25-27 Jan. (on CD-ROM).

Kocaman S., Casella V., Franzini M., Gruen A., 2007a. The triangulation accuracy of ADS40 imagery over the Pavia Testsite. Proceedings of Annual Meeting of U.K. Remote Sensing and Photogrammetry Society 2007, together with the ISPRS Comm. I WG 4 "Airborne Digital Photogrammetric Sensor Systems" Workshop, Newcastle upon Tyne, U.K., 12-17 September (on CD-ROM).

Kocaman S., Gruen A., Casella V., Franzini M., 2007b. Accuracy Assessment of ADS40 Imagery over the Pavia Testsite. Proceedings of Asian Conference on Remote Sensing 2007, Kuala Lumpur, Malaysia, 12-16 November (on CD-ROM).

Sandau, R., Braunecker, B., Driescher, H., Eckardt, A., Hilbert, S., Hutton, J., Kirchhofer, W., Lithopoulos, E., Reulke, R., Tempelmann, U., Hinsken, L., Recke, U., 2003. ADS40 Calibration and Verification Process. Proceedings of the 6<sup>th</sup> Conference on "Optical 3D Measurement Techniques", Zurich, Switzerland, 22-25 September, pp. 48-54.

Saks T., Tempelmann U., 2008. ADS40 system with new sensor heads – key to the simplified model for self-calibration and extended user benefits. EuroCOW 2008 International Calibration and Orientation Workshop, Castelldefels, Spain, 30 January-1February (on CD-ROM).

Tempelmann, U., Hinsken, L., 2007. Hardware improvements of the ADS40 sensor heads SH51/52 and how they allow a better camera model for self-calibration. Proceedings of the 8th Conference on "Optical 3D Measurement Techniques", Zurich, Switzerland, 9-12 July, pp. 187-193.

Wicki, S., 2000. Design Principle of The LH Systems ADS40 Airborne Digital Sensor. *The International Archives of Photogrammetry and Remote Sensing*, Amsterdam, Netherlands, Vol. 33, Part B1, pp. 258-265.