RADIOMETRIC AND GEOMETRIC EVALUATION OF THE CAPABILITIES OF THE NEW AIRBORNE DIGITAL PHOTOGRAMMETRIC SENSORS

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ABSTRACT:

In this paper the theoretic and practical points of view about the applications of the modern digital airborne sensors in the photogrammetry and remote sensing fields are described. The first part of the paper describes the theoretic matter, the second one shows the first results regarding the carried out elaborations on an image of Palermo acquired by digital airborne sensor LH System ADS40. Besides the research has examined most of sides regarding the trilinear sensor and it has highlighted the capabilities and limitations respect to the traditional analogical system and the matricial CCD sensor.

1. INTRODUCTION

1.1 Brief historical introduction

In the last ten years the digital airborne sensors have been developed in order to carry out several Photogrammetry and remote sensing applications. The development has been feed by two different fields: the research about the satellite platform and the technologic request by the users of photogrammetric techniques. The digital epoch starts with the diffusion of the first CCD sensors and of the computer graphic. The last step regard the decreasing of the difference between photogrammetric and remote sensing applications.

1.2 Paper development description

In the carried out experimentation the next steps have been explorated:

- Description of the theory about the sensors digital;
- description of the pushbroom sensor Leica (LH System) ADS40;
- the photogrammetric digital process: from the sensor calibration to the orthorectification;
- capabilities of the digital ADS40 images both for the geometric accuracy and for the features extraction

The digital airborne camera can be classified in two big families: the pushbroom sensor characterized by linear sensor and the frame camera equipped with a matricial CCD. The pushbroom sensor can be classified in:

- monochromatic scanner;
- multispectral scanner;
- hyperspectral scanner;
- trilinear scanner.

For the high scale cartography application the most suitable is the trilinear sensor.

The discussion about the two technologies, pushbroom and frame camera, is actual and in this paper the merits and defectives of the both kind of sensors have been compared.

1.3 Comparison between two technologies

The first big vantage of the matricial sensor regards the Ground Sample Distance (GSD), in fact the matricial sensors provide higher geometric resolution images. In the trilinear sensor is really difficult to acquire images with geometric resolution higher than ten centimetres. For this reason the trilinear sensors can't be applied in very high scale mapping. The pushbroom camera doesn't present any intrinsic geometric accuracy. An acceptable geometric accuracy is just obtained by an internal GPS/IMU system. The geometric accuracy is limited by the accuracy of the vehicle position acquired by DGPS technique. This value is less precise for a vehicle in movement about ten centimetres for each array.

For the matricial sensor the photogrammetric restitution process is similar to the already known photogrammetric one adopted for the films camera, instead, for the pushbroom sensor the use of the mathematical model is requested. The trilinear sensors allow to obtain an orthophoto with good quality and geometric accuracy just few hours after the acquisition without the use of Ground Control Points (GCP).

The acquisition procedure is really different between the two methodologies: the frame camera produces images referable to a central perspective; in the opposite, the trilinear digital sensors provide three or more images influenced by the orientation angle of each CCD line. The nadiral linear sensors are called "pseudo – orthogonal".

In the multispectral matricial CCD sensors, in order to obtain the same pixel size for each band, some lens are used.

Otherwise the trilinear sensors allow to acquire an panchromatic, a RGB and a false colour image using the same optical devise and focal plane.

Respect to the frame camera, the pushbroom sensors permit to reduce the number of the strips.

2. TRILINEAR SENSORS

The possibility to dispose three panchromatic lines on the same focal plane with one more multispectral line has been demonstrated by a research carried out in Germany from 1970 (Albertz et al - 1996; Sandau and Bärwald - 1994; Sandau and Eckardt - 1996).

The disposition of the lines on the same focal plane is showed in the fig. 1: in particular, three panchromatic arrays (black) provide the ground geometry and the stereoscopy, instead the additional lines, whose sensitivity is checked by filters, provide the multispectral information (RGB e NIR). In this article just the ADS40 sensor is described.

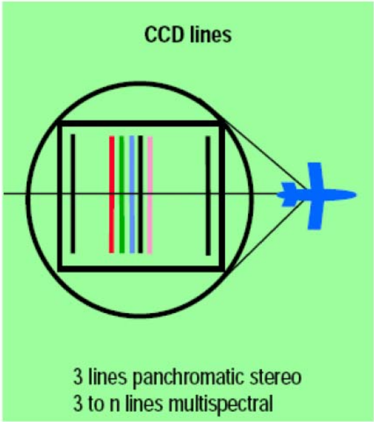

Figure 1. Focal plane arrangement

2.1 Leica (LH Systems) ADS40

The ADS40 (*Aerial Digital Sensor)* is a trilinear sensor and it has been developed by LH Systems with the collaboration of the aerial- spatial German institute (Deutsches Zentrum für Luft- und Raumfahrt – DLR).

The optical devises of ADS40 sensor are projected for high resolution photogrammetric and remote sensing applications. The system of lens is similar to the one of the film camera RC30 but the recording procedure is really different. In the film camera the minimization of the distortions is a primary aim, instead in the lenses of the digital camera the most important characteristic is constituted by the telecentricity of the lens in direction of the focal plan where the image is formed.

This characteristic is useful for every digital camera but it represents a factor absolutely criticize for the ADS40 sensor and very indispensable for the recording of the narrow multispectral band. The focal plan is constituted by four CCD slots: two of these contain the single CCD and two slots contain the triple lines.

The development of the technology of the focal plan working foresees the evaluation of the alignment accuracy of the CCD sensors, the control of the CCD sensors temperature and the interfacing between the optic devise, the filters and the environment of management.

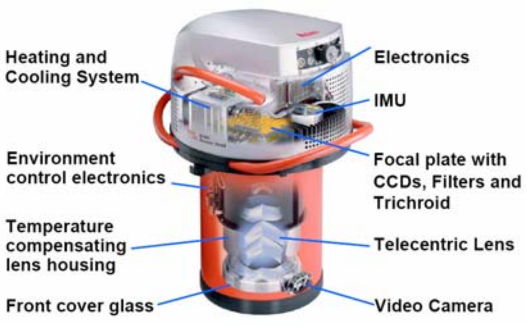

Figure 2. ADS40 sensor head

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The focal plan of the sensor hosts some CCD arrays. Theirs configuration is changeable in function of the customer request. The standard configuration of the CCD line is constituted by:

- A pair of CCD panchromatic arrays with 12000 pixel. These arrays are oriented forward and they differ each other of half pixel. This planning solution, with the half pixel difference, allows to obtain images without aliasing effect.
- A pair of CCD panchromatic arrays with 12000 pixel. These arrays have a nadiral orientation and they differ each other of half pixel and are joined to one more linear sensor used for the near infrared wavelength.
- A pair of CCD panchromatic arrays with 12000 pixel. These arrays have a backward orientation and they differ each other of half pixel.
- Three RGB multispectral arrays with 12000 pixel with nadiral orientation.

This configuration foresees three panchromatic bands. Every band is composed by a CCD relocated couple with 12000 pixel and four multispectral bands composed by 4 CCD single arrays. The pixel size is 6.5 µm for every line. Therefore Each CCD array is disposed a length of about 8 cm. The CCD vector are arranged in such a way to produce a transversal Field of View (FOV) of 64°. The stereoscopic angles according to which the CCD lines are disposed are of 14.2° e 28.4° (fig. 3).

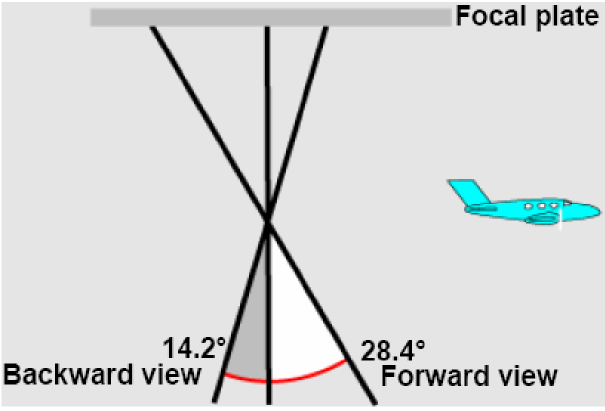

Figure 3. Stereoscopic angles

The asymmetric disposition of the CCD lines brings some substantial benefits:

- the possibility to choose three different configurations of stereoscopic vision (Forward/Nadir – 28.4°, Backward/Nadir – 14.2°, Forward/Backward - 42.6°);
- to avoid singularities in the mathematical model.

The equivalent focal length of the camera is 62.77 mm. The optical device of ADS40 sensor is called DO64 (Digital Optics). The telecentric lens represents the main part of the DO64. This devise allows to the optical rays to hit the focal plane perpendicularly. The acquisition is not comparable with a central perspective but in this case it is called "pseudo-orthographic".

2.2 Second generation ADS40

The new generation ADS40 sensors allow to acquire five co-registered bands without the pansharpening procedure. This capability is pledged by a new patented beamsplitter called tetrachroid. The second generation ADS40 is characterized by two new heads: SH51, SH52. These heads are smaller and following the technical features are described:

- The SH51 sensor head is equipped with only one tetrachroid filter. Its application field is mainly the orthophotos production.
- The SH52 sensor head has two tetrachroid filters and is destined to a generic use (remote sensing and photogrammetric applications). The SH52 besides able to acquire stereoscopic, RGB and NIR images.

The sensor is equipped with a new inertial positioning system: Leica IPAS10.

The following figures 4,5 and 6 show the technical features of the 2nd generation ADS40 sensor.

Figure 4. SH51 and SH52 sensor heads

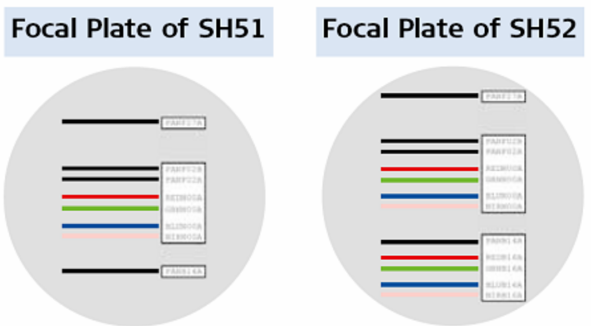

Figure 5. SH51 and SH52 arrays arrangement

Mapping Accuracies

Average GSD with ADS40	Map Scale	Map standard x-y accuracy RMSE	contour interval
5-10 cm	1:500	0.125 m	0.25 m
10-15 cm	1:1000	0.25 m	0.5 m
15-20 cm	1:1500	0.40 m	0.75 m
20-30 cm	1:2000	0.50 m	1 m
25-35 cm	1:2500	0.60 m	1.25 m
30-50 cm	1:5000	1.25 m	2.5 m
40-60 cm	1:10000	2.50 m	5 m
50-70 cm	1:20000	5.00 m	10 m
50-80 cm	1:25000	6.25 m	12.5 m
50-100 cm	1:50000	12.5 m	20 m
50-100 cm	1:100000	25 m	50 m

Figure 6. ADS40 2nd generation mapping accuracies

3. THE PHOTOGRAMMETRIC PROCESS FOR TRILINEAR DIGITAL SENSORS

3.1 Sensor calibration

The calibration process of ADS40 imagery has been carried out in DLR (Germany) and has been developed starting from the technology used for the spatial sensors with the addition of infrared band.

There are two different phases of laboratories:

- Geometric calibration. During this phase a really precise measurement of the position of every pixel in a intrinsic reference system has performed.

- Radiometric calibration. During this phase the PRNU (Photo Response Non Uniformity) is corrected. This error is caused by the different manufacture and shading of the detectors.

3.2 Mission, flight and acquisition

As it is already known, before the acquisition a flight plan have to be drafted. The flight altitude is chosen in according to requested GSD. The GSD increases of about 10 cm for each rise of 1000 metres flight altitude.

The acquisition is simultaneous for every CCD array and it is aided by a GPS/INS system. The flight strip is continues and the along - track overlap for the three images is about 99%. The unprocessed scenes are characterized by high distortions due to the airplane movement. The unprocessed scenes are called "Level 0" images.

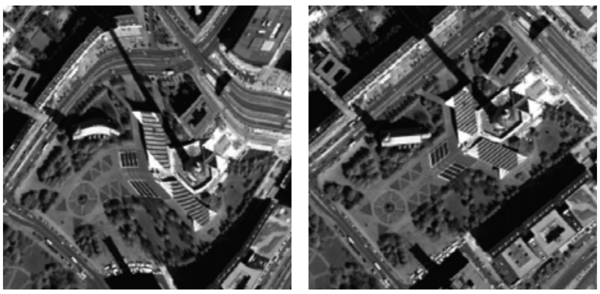

Figure 7. (left) L0 image example – (right) L1 image exaple

The DGPS technique ensures a position sensor accuracy lower than 10 cm. The IMU system acquires 200 values of attitude angles for second. Although the frequency acquisition of the GPS/IMU data is really high it is not continues.

3.3 Mathematical model and bundle adjustment

The pushbroom multilinear ADS40 sensor requests mathematical models more complex than the usual collinearity equations. The bundle adjustment has been carried out by Leica ORIMA software.

The technical specifications of the GPS/IMU are not able to provide a suitable precision in according to the accuracy requested for the high scale mapping. In order to obtain a high accuracy a bundle adjustment process is required. The aerial triangulation is also used to calibrate some system parameters. For example the aerial triangulation process allows to evaluate the antenna offset and the misalignment of the gyro system axes.

4. THE EXPERIMENTATION

4.1 Available Images

This research has been arranged within a collaboration with the CGR of Parma. In particular, the CGR company has provided three L0 and L1 strips (PanF, Green Nadir, PanB, RGB and NIR) relative to the country of Palermo:

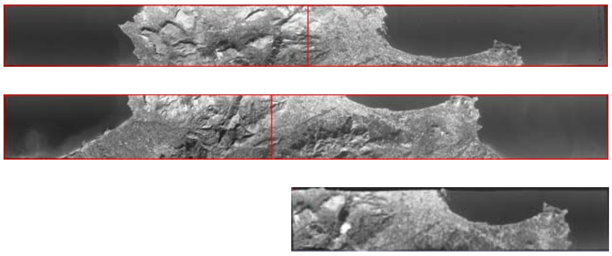

Figure 8. the three ADS40 strips

4.2 Automatic DTM extraction tests

A module of automatic extraction of digital terrain models is available in the SOCET SET DPW. This module is called ATE (automatic terrain extraction) and it can be used just when the stereoscopic oriented pairs are available.

In order to calculate the elevation by a stereoscopic oriented pairs there are two ways:

- the adaptive method;
- the not adaptive method.

The carried out experimantation has highlighted that the results of DTM extraction are influenced by a wide set of variables:

- presence of buildings or forest trees;

- choice of the stereo pair. For every scene three stereo models are available: Forward/Nadir, Forward/Backward and Nadir/Backward. Besides, if the flight strips are characterized by an across - track overlap the number of the stereo pairs increases because the number of possible permutations increases too. In fact, in the study case (9 images), the possible stereo pairs are 27. the most favourable stereo pair seems to be that nadir/Backward.

- choice of correlation algorithm. The numerous carried out testes have demonstrated that the automatic extraction doesn't provide a totally satisfying DTM but some corrections are almost always necessary. In the following fig. 4 two DTMs extracted from stereo pair nadir/backward are showed.

4.3 The influence of GCP in triangulation process

The bundle adjustment has been performed by ORIMA-D software. ORIMA allows to perform all the orientation processes but it is mainly a powerful triangulation software. In order to evaluate the influence of the GCP in the triangulation process 4 Check Points (CP) have been fixed and the number of GCP has been increased from 0 to 9.

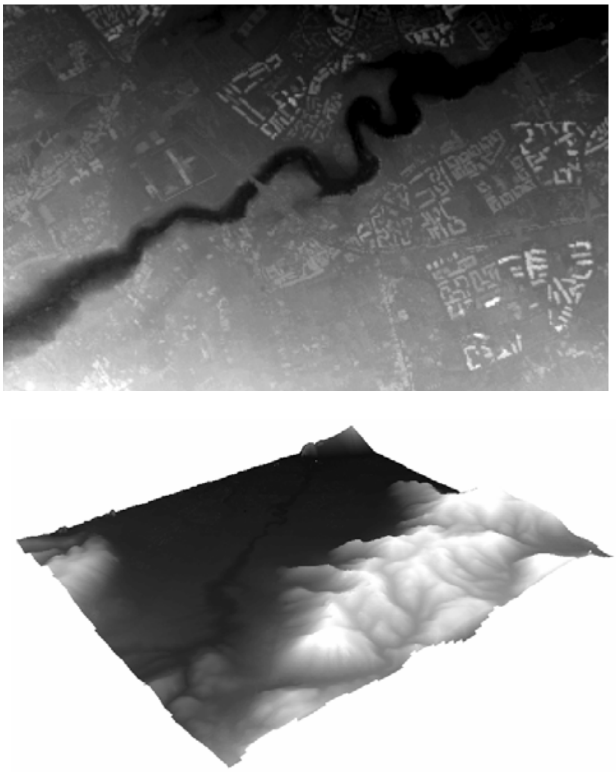

Figure 9. DTMs of Palermo

In the most common DPW the user can choose which points will be GCP or CP by a label. The ORIMA methodology is quite different: for every point an "a priori" standard deviation (sigma0) must be fixed. The sigma0 value is chosen in order to obtain a local redundancy parameter near to 1. The results of carried out triangulations, both for the GCP and the CP, have showed a RMS value lower than a pixel (60 cm) for each GCP configuration.

4.4 The near infrared band. At-sensor radiance calculation. The NDVI vegetation index.

The most simple radiometric model used for the CCD sensors is the linear one. In this model the Digital Number values depend on the calibration factor C1 and offset C0:

$$L = C_1\ DN + C_0 \qquad (1)$$

where L is the at-sensor spectral radiance.

In the ADS40 model the C0 value is corrected by procedures carried out in the laboratory. In this way the C0 value is practically equal to zero. As the dependence on the integration time is linear the following calibration factor, called specific, can be defined:

$$c_1 \equiv C_1\ t \qquad (2)$$

$$L = \frac{c_1\ DN}{t} \qquad (3)$$

The specific calibration factor has a constant value for the sensor and its unit of measurement is W s m-2 sr-1 µm-1 DN-1]. Its value is provided in the calibration file of ADS40 images and it corresponds to the RADIOMETRIC GAIN string.
In order to obtain a 16 bit unsigned data value the Digital Number (DN) is multiplied by 50. The Calibrated Digital Number CDN is the product between the DN and 50.

$$CDN = DN * 50\ c_1 / t \qquad (4)$$

The L1 images contain just CDN values.
The value of "at sensor radiance" can be calculated with the simple following equation:

$$L = CDN/50 \qquad (5)$$

This equation is applicable just for the L1 images.
In this application the "at sensor radiance" has been calculated for the red and infrared bands.

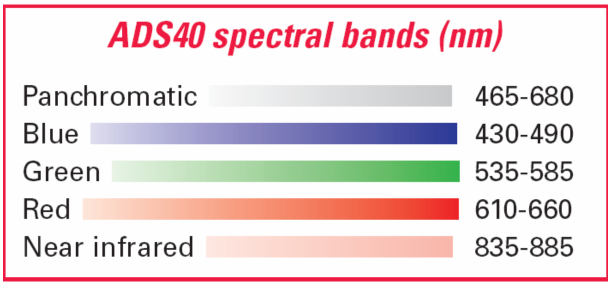

Figure 10. ADS40 spectral bands

The calibrated images allow to calculate the vegetation indexes. The most common vegetation index is the NDVI (normalized difference vegetation index). It is obtained by a ratio between the red and infrared bands.

The figure 11 illustrates the NDVI image extracted for the "Parco D'Orleans" area.

The presence of the infrared band is the first step toward the reduction of the differences between photogrammetric and remote sensing application. Otherwise, the only presence of the infrared band is not enough for all the remote sensing applications. An increase of radiometric and spectral resolution would be welcome.

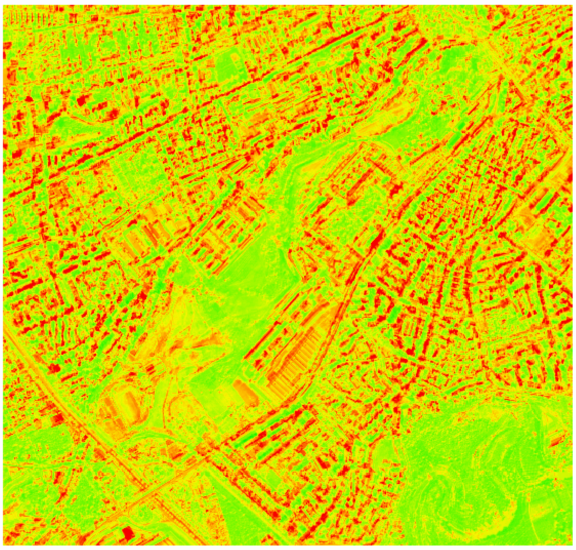

Figure 11. NDVI image

5. CONCLUSIONS

It is already known that the film camera industries are going to stop the production of photogrammetric film. In this way the airborne digital cameras will become the only available acquisition system. Both in the new technologies and in the research field the many steps forward have been taken. Nevertheless, the development of these sensors must and can progress: a higher geometric resolution can allow all the very high scale mapping applications. The spectral and radiometric resolution should be increase to permit more remote sensing applications. This research study will be developed and the carried out experimentations are going to study in depth. The second generation sensors will be tested and the research about the infrared band applications will be further developed.

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REFERENCES

Kocaman S., Casella V., Franzini M., Gruen A., 2007. The triangulation accuracy of ADS40 imagery over the Pavia Testsite. ISPRS Workshop on Digital Cameras together with the Annual Meeting of U.K. Remote Sensing and Photogrammetry Society, Newcastle upon Tyne, U.K.

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

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. (proceedings on CD-ROM).

AlHamlan, S., Mills, J. P., Walker, A. S., Saks, T., 2004. The influence of ground control points in the triangulation of Leica ADS40 data. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 35(B1): 495–500.

Hinsken L., Miller S., Tempelmann U., Uebbing R., Walker S., 2002. Triangulation of LH System’ ADS40 imagery using ORIMA GPS/IMU. ISPRS Commission III, Symposium 2002, September 9-13, 2002, Graz, Austria, (proceedings on CD-ROM).

Börner A., Reulke R., 2001. Results of Test Flights with the Airborne Digital Sensor ADS40. R. Klette, S. Peleg, G. Sommer (Eds.), International Workshop RobVis 2001, Springer 2001, ISBN 3-540-41694-3, pp. 270-277.

Fricker P., 2001. ADS40 – Progress in digital aerial data collection. In: D. Fritsch, R. Spiller (Eds.), Photogrammetric Week '01, Wichmann Verlag, Heidelberg, pp. 105 - 116.

Haala N., Fritsch D., Stallmann D., Cramer M., 2000. On the performance of digital airborne pushbroom cameras for photogrammetric data processing - a case study. International Archives of Photogrammetry and Remote Sensing, Vol. 33, Part B4/1, pp. 324-331.

Gwinner K., Hauber E., Hoffmann H., Scholten F., Jaumann R., Neukum G., Puglisi G., Coltelli M., 1999. The HRSC-A Experiment on High Resolution Multispectral Imaging and DEM Generation at the Aeolian Islands. 13th Int. Conf. on Applied Geologic Remote Sensing, Vancouver B.C., March 1999, Vol. I, pp. 560-569.

Fritsch D., 1997. Experiences with the Airborne Three-line Photogrammetric Image Acquisition System DPA. In: D. Fritsch, D. Hobbie (Eds.), Photogrammetric Week '97, Wichmann Verlag, Heidelberg, pp. 63-74.

Henricsson, O., 1996. Analysis of Image Structure using Color Attributes and Similarity Relations. Ph.D. Thesis, Report No.59, Institute of Geodesy and Photogrammetry, ETH Zurich, Switzerland.