AN ITALIAN RESEARCH PROJECT ON DIRECT PHOTOGRAMMETRY

R. Galetto, V. Casella, M. Franzini, A. Spalla

DIET – University of Pavia, via Ferrata, 1- 27100 Pavia, Italy
(riccardo.galetto, vittorio.casella, anna.spalla, marica.franzini) @unipv.it

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ABSTRACT:

The paper deals with an Italian research Project on direct photogrammetry, active in the period 2003

b. Preparation of a test-site, execution of test-flights, distribution of the material to the various units as described in section 4 and 5 (Casella, Galetto, 2003).

2.2 Objectives of the second year of research (2004)

c. Definition of refined methodologies based on Kalman filtering of the measurements acquired by the sensors.
d. Refined methodologies for sensor calibration: direct sensor integration versus integrated sensor orientation (Pinto, Forlani, 2004).
e. Stability of calibration of the GPS/IMU sensor.
f. Influence of bad GPS constellation and/or cycle slips.
g. Individuation of suitable methodologies for local parallax reduction (Casella, Franzini, 2003; Casella, 2004).
h. Individuation of intrinsic methodologies in order to check the reliability of GPS/IMU data, without resorting to airborne triangulation, and without measuring control points on the ground.
i. Analysis of the main commercial photogrammetry software in order to check their functionality related to GPS/IMU data.
j. Drawing up guidelines for the execution and the testing of GPS/INS aided photogrammetric flights.

3. DEVELOPMENT STATUS OF THE PROJECT

The objectives of the first year have been substantially reached. Regarding item b., the test site has been completed and measurements are finished. Flights were performed successfully. All the data has been delivered to the units. The only running task of this part is the measurement of the image coordinates of all the control points (around 250) and of 18 tie points per image, for all the acquired images. This is a large job carried out by a joint effort of four units, that will soon give each researcher the possibility of using a huge amount of image measurements, without loading any photogram. Therefore researchers will be free to perform new measurements, or to focus on the algorithmic part of their research. Moreover, the *official* image coordinates, after a good data rejection job, will constitute a common basis for effectively comparing different approaches and algorithms.

The evaluation of a vast set of images acquired in an industrial context has been performed, giving interesting results. As this is a significant part of the Project, the following section describes its motivation, while the main results obtained are illustrated in another paper (Casella et al., 2004).

Regarding the activities of the second year, currently (April 2004) all the units started investigating the topics. Some groups have already published papers related to the items from c. to j.: the Pavia's unit worked on local parallax reduction (Casella, Franzini, 2003; Casella, 2004) and Parma's unit worked on refined calibration (Pinto, Forlani, 2004).

3.1 Study of the quality of the exterior orientation obtained in an industrial context

Quality assessment of direct georeferencing in photogrammetry is of great interest because this technology is developing rapidly and the case studies already acquired are significant but not exhaustive. Besides, many of the most significant tests, such as the OEEPE test and those performed by the University of Stuttgart, were conducted with dedicated data, which was acquired exclusively for research purposes. Such studies are useful because they allow estimation of the quality which is attainable using a certain technology in the best possible way; nevertheless it is important to ascertain what the attainable quality in an ordinary daily work-flow is and how high it's reliability.

This is the precise aim of the described step of our Project, which has two main goals: a systematic evaluation of residual parallaxes, which are sometimes critical in directly oriented images, and a systematic assessment of accuracy. The considered data is of purely industrial origin and furthermore, the vast and heterogeneous case study - different cities, different flights, different calibrations - make the described test very significant and reliable.

To perform this phase the nine working groups, belonging to different cities, were given a block above each city, together with EO data measured by an inertial integrated sensor. The data was supplied by the Italian company Compagnia Generale Ripreseaeree - CGR, whose headquarters are in Parma, which joined the Project. The images were acquired before the beginning of our Project, within an industrial programme called *TerraItaly-City*.

This program has been performed from 2000 to-date and deals with the production of high detail colour orthophotos for more than 110 Italian cities at a nominal scale of 1:2000. Images were acquired with a Leica RC30 camera, provided with an Applanix POS/AV 510 sensor. The focal length of the lens was 300 mm; the average relative height of the flight was 2900 m; the average image scale, 1:9300. The digital images were produced by a Zeiss SCAI scanner with a resolution of 14 microns per pixel. The resulting GSD is 12 cm.

This part of the Project is of great interest because the nine blocks considered were acquired before the beginning of our research Project, following the ordinary daily work-flow of the company. Results for this part of the Project are reported in (Casella et al., 2004).

4. PAVIA'S TEST SITE

Pavia's test site has many relevant features which have been developed in the last five years, according to the needs of the ongoing research projects. Some further features have been created from scratch, to fully support the execution of the Project under description.

4.1 GPS and levelling network

There is a high-quality GPS network, constituted by 13 vertices. It was established in summer 1999 and successively extended and repeatedly re-measured. It has been surveyed with the static mode and with long-lasting sessions. The network is connected to the Italian GPS network, called IGM95, which is a materialization of the ETRS-89 datum. It embraces all of Pavia and its neighbourhood, as Figure 1 shows. It also includes a GPS permanent reference station operated by the *Laboratorio di Geomatica* of the DIET Department of the University of Pavia.

The network is frequently used, for many tasks, so it is continuously under verification. The last adjustment was performed with a relative redundancy of 8.5 that is, 8.5 baselines were used to determine each point, in the average. Results are summarized in Table 1.

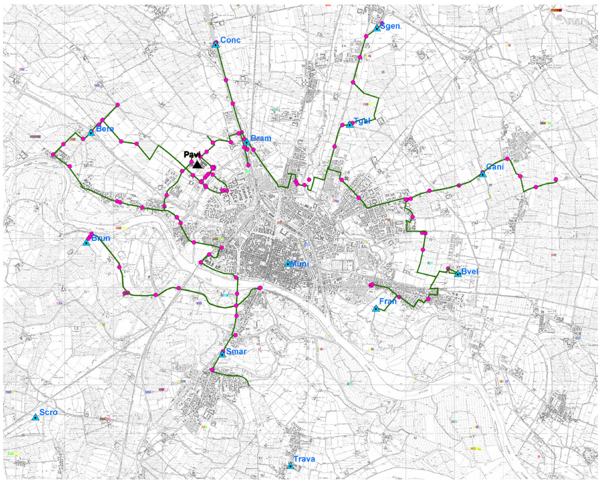

Figure 1. Pavia's GPS and levelling networks. Blue triangles are the GPS network vertices, red circles represent levelling benchmarks, green lines are levelling paths. The black triangle represents the GPS permanent reference station

	Min	Max	Mean	Std
e	0.12	0.44	0.220	0.097
n	0.09	0.42	0.181	0.097
u	0.42	1.28	0.607	0.237

Table 1. Mean statistical parameters of standard deviations s of the network vertices, referred to a local Cartesian coordinate system, measured in centimetres

The greater part of the network's points have been connected by geometric levelling, so that we know, for each levelled point of the network, the ellipsoidal height, as well as the orthometric height. This allowed us to estimate a very detailed model of geoid undulations: we verified that its mean square error is around four centimetres.

4.2 Cartography

There are many different cartographies concerning Pavia. Their scales range from 1:500 to 1:100.000. Table 2 summarizes the main features of those characterized by large/medium ratio scale.

Scale	Support type	Covered area	Owner	Production/last update
1:500	Paper & raster	City Centre	Pavia city	1984
1:2000	Paper & vector	The whole city territory	Pavia city	1982/2000
1:10000	Paper & raster	The whole regional territory	The Lombardia region	1983/1994

Table 2. Main characteristics of the available cartographies concerning Pavia

Moreover we have a colour orthophoto whose GSD is 12 cm, produced in the year 2000 by the Italian company CGR within its TerraItaly City program. The company kindly granted us the use of the photographs, free of charge.

4.3 Lidar datasets

There are several lidar datasets acquired with different sensors: Optech 1210, Toposys I, Optech 3033.

4.4 Check areas for lidar datasets

There are check areas constituted by GPS and classical ground surveying measurements of flat areas, such as tennis courts and car parks, and of ramps.

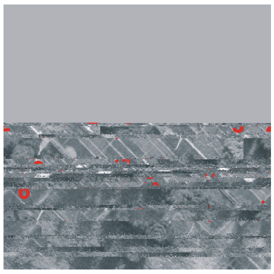

Figure 2. Example of a flat check area

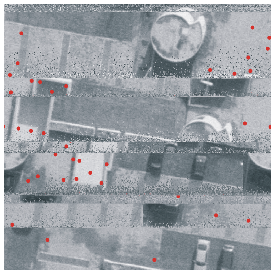

Figure 3. Example of a check area constituted by a ramp

4.5 The AGCPs set

The first set of ground control points is constituted by 169 artificial ones which are white squares of 35 cm. They homogeneously cover the whole test site, which is 6 x 4.5 km wide.

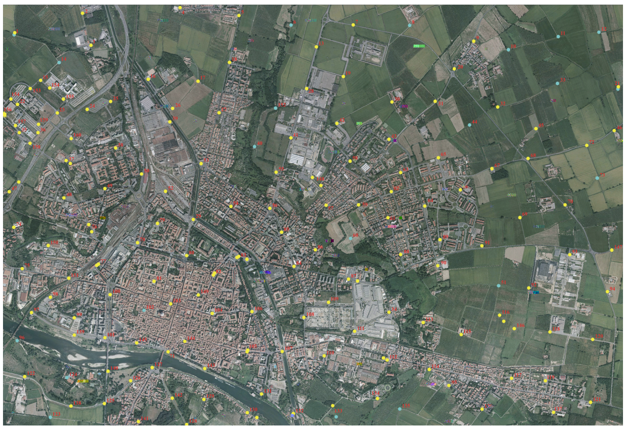

Figure 4. Distribution of the AGCPs over the test site

The aerial images which have been acquired over Pavia have scales of 1:5000, 1:8000 and 1:18000, which are generally used in Italy to produce maps at the scales 1:1000, 1:2000 and 1:10000. The size of the markers has been carefully tuned in order to have optimal vision on aerial images whose scale is in the range 1:5000 – 1:8000. Nevertheless, the markers are usually visible on the 1:18000 images, although with difficulty. Prior to the creation of the complete set of markers, we created a couple of test sites, constituted by samples of different sizes and shapes, shown in Figure 5 and Figure 6.

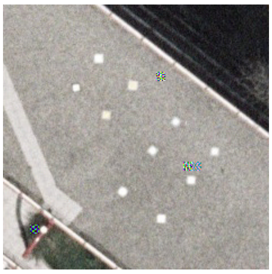

Figure 5. Samples of mobile artificial markers

Figure 6. Samples of painted artificial markers

These samples helped us in determining the final size of the markers. Most of the markers have been painted directly on the ground, mainly on roads or other flat concrete structures. When this hasn't been possible, in rural parts of the test site, we have installed artificial mobile ones, made of metal, as Figure 7 and Figure 8 show.

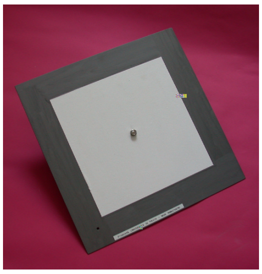

Figure 7. Laboratory image of a mobile marker

Figure 8. An installed mobile marker

As previously stated, visibility of the markers is very good for 1:5000 and 1:8000 images and is satisfactory for the smaller 1:18000 scale, as Figure 9, Figure 10 and Figure 11 show.

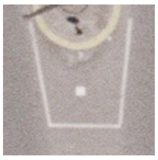

Figure 9. Visibility on a 1:5000 image

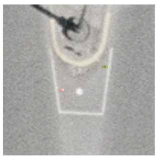

Figure 10. Visibility on a 1:8000 image

Figure 11. Visibility on a 1:18000 image

The AGCPs have been measured with GPS in the fast static mode, using three fixed receivers, set up on vertices of the GPS network, forming an equilateral triangle. The relative redundancy of the adjustment is therefore three, and results are very good, as Table 3 shows.

In order to point out and eliminate set-up gross errors, all the AGCPs have been re-measured.

	Min	Max	Mean	Std
e	0.16	0.80	0.437	0.134
n	0.16	0.73	0.321	0.094
u	0.33	1.50	0.895	0.246

Table 3. Mean statistical parameters of standard deviations s of the 169 AGCPs, referred to a local Cartesian coordinate system, measured in centimetres

4.6 The NGCPs set

Even though the AGCPs play a key role in the Project, we decided to create a smaller set of natural GCPs, because they are visible in images acquired before the creation of AGCPs: we have five photogrammetric blocks acquired with a GPS/IMU aided camera before the start of the Project. Moreover, we are also interested in estimating the attainable precision on natural points, which are usually less well defined than artificial ones. Up to now we have 62 well distributed NGCPs.

Figure 12. Distribution of the NGCPs over the test site

These points have been carefully chosen in order to avoid perspective effects, as much as possible, because they must be visible on many different images. For this reason we looked for features belonging to flat surfaces such as roads, courts, etc.

Figure 13. Visibility on a 1:5000 image

Figure 14. Visibility on a 1:8000 image

Figure 15. Visibility on a 1:18000 image

NGCPs have been measured with GPS in the fast static mode, with the same schema used for AGCPs. The relative redundancy of the adjustment is three, and results are quite good, as Table 3 shows. NGCPs have been completely re-measured, too, in order to reject bad data.

	Min	Max	Mean	Std
e	0.17	0.76	0.392	0.146
n	0.14	0.79	0.326	0.150
u	0.41	1.49	0.831	0.313

Table 4. Mean statistical parameters of standard deviations s of the 62 NGCPs, referred to a local Cartesian coordinate system, measured in centimetres

Flight	Date	Scale	Date	Focal length	Relative flight height	Overlapping	Strips number	Images number
1	14/5/2003	1:5000	14/05/03	150 mm	750 m	60/30	8	139
		1:8000	14/05/03	150 mm	1200 m	60/60	11	131
		1:18000	14/05/03	150 mm	2700 m	60/60	2	19
2	16/05/03	1:5000	16/05/03	150 mm	750 m	60/30	8	135
		1:8000	16/05/03	150 mm	1200 m	60/60	11	128
		1:18000	16/05/03	150 mm	2700 m	60/60	2	15
3	06/04/03	1:5000	06/04/03	300 mm	1500 m	60/30	8	146
		1:8000	06/04/03	300 mm	2400 m	60/60	11	145
4	17/03/03	1:8000	17/03/03	300 mm	2400 m	60/60	11	135

Table 5. Summary of the performed flights

5. FLIGHTS PERFORMED OVER PAVIA'S TEST SITE WITHIN THE FRAME OF THE PROJECT

Four different flights have already been performed over the test site, by the Italian company CGR, whose planes are equipped with Applanix POS/AV 510 sensors. Two of them have been acquired with a camera whose focal length is 300 mm, while the others have been taken with a 150 mm camera. The flights are composed of a certain number of blocks, flown at different heights and characterized by the scales 1:5000, 1:8000 and 1:18000. As previously stated, these image scales are usually used in Italy to produce maps respectively at the scales 1:1000, 1:2000 and 1:10000. Flights are usually distinguished between calibration and test flights, in the direct photogrammetry literature. The first are used to calibrate the sensor, while the second are used to assess precision and quality. They should be as independent as possible. We chose to perform complex flights which allow the user to follow several different strategies of calibration and testing. Moreover, the blocks have a complex structure themselves, to fulfil the need of independently estimating the calibration parameters. Another motivation for such a complex structure is to allow intrinsic quality assessment, that is without external control measurements.

Flights 1 and 2 have been acquired with a Wild RC30 camera, equipped with a 150 mm lens. They are composed of three blocks whose structure is shown in Figure 16, Figure 17 and Figure 18. The **1:5000 block** has three ordinary parallel strips covering a part of the test site, flown in an East-West direction. The first strip, once completed, is immediately re-flown in reverse. There are two cross strips, at the head and tail of the block; each of them is re-flown in reverse at the end. The along-track overlapping is 60%, while the across-track one is 30%. The number of images taken is around 140.

The **1:8000 block** has seven ordinary parallel strips covering the whole test site, flown in the East-West direction. The first one is flown back and forth. There are two cross strips, at the head and tail of the block; each of them is flown back (at the end) and forth (at the beginning). The along-track overlapping is 60%, as well as the across-track. The number of images is around 130.

The **1:18000 block** has a very simple structure and is constituted by two strips flown in the East-West direction, with the 60/60 overlapping. The number of images taken is around 20.

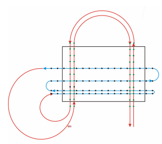

Figure 16. Structure of the 1:5000 block

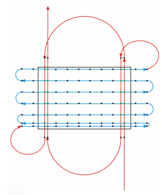

Figure 17. Structure of the 1:8000 block

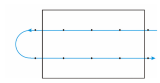

Figure 18. Structure of the 1:18000 block

Flights 3 and 4 have been acquired with a Wild RC30 camera, equipped with a 300 mm lens. Their structure is similar to that of flights 1 and 2, but not the same. Indeed, we decided not to acquire images at the 1:18000 scale, because this would have required a high-altitude flight, and good results were not guaranteed. **Flight 3** is composed of the 1:5000 and 1:8000 blocks, having the structure described above. **Flight 4** is composed only of the 1:8000 block.

Table 5 summarizes the main parameters of the flights. It is noticeable that the total number of images is around 1000. Considering they are colour images, scanned with a pixel size of 14 microns, each image occupies 800 MB. The whole set has a size of 800 GB, corresponding to 200 DVDs. As we use tiled TIFF files, JPEG-compressed, the size of each image can be reduced to 180 MB and the whole set corresponds to approximately 50 DVDs.

It is clearly possible to conceive various strategies for calibrating and testing the flights. It is also possible to calibrate with only one block or with two or even three, in order to be able to estimate the true focal length. As we have already pointed out, the complex structure of the flights, has the main advantage of allowing the uncorrelated estimation of the calibration parameters and of the camera self-calibration model.

6. CONCLUSIONS

The paper describes the research Project, the test site and the test flights. The Project is under development: although it is well defined, it is still open to adjustment, depending on the results of the Workshop. All the scheduled flights have been performed, although it is possible that we will decide to undertake further flights, in case it should prove useful.

The test site is continuously under maintenance and development. We would be pleased to offer it in support of other research projects. Indeed we think of it as a contribution to this continually growing and unique area of European research.

7. ACKNOWLEDGMENTS

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