

## **An Italian national research project on inertial positioning in photogrammetry**

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### **1. Abstract**

The paper deals with an Italian research project on direct photogrammetry, active in the period 2003-2004. We describe the goals of the Project and its phases. We also describe the test site that has been constructed in Pavia and the several ad-hoc flights which have already been performed over it.

### **2. Research Projects in Italy**

Before entering into the heart of this matter, we think it is appropriate to give some information about research program financing in Italy.

Research projects whose size is not great can be financed by public agencies or by universities; but the largest ones are financed by The Ministry of University and Scientific Research (MIUR). Yet they aim to award only research projects which are appointed as “relevant for the national interest” and generally speaking they concern projects backed by different universities.

The mechanism according to which one of these projects originates and develops is the following: every year MIUR issues a notification inviting university professors to put forward projects; the costs of the projects which are approved are then covered by MIUR at a rate of 70%.

Every professor who wants to apply, outlines a research project which is spread, via the internet, to the whole Italian scientific community. The professors who belong to other Italian university centres have the possibility to form research units and join the project as aggregate research units to the unit put forward by the proposing professor, who is the leader both of the project as a whole and of his own research unit.

Each unit has to estimate the cost of the activities which it is going to carry out and must ensure that it has the possibility to finance at least 30% of the expenses with its own funds.

All the projects have to be checked by national and international arbitrators, whose judgements are not divulged, and who assign each project a merit score. Only high scoring projects are accepted by MIUR, which in that case covers the cost of the research project.

The research project described in this paper is a research project drawn up in 2002 in order to be developed in 2003 and 2004, which has been rewarded by MIUR as “relevant for the national interest”. The project leader is Professor Galetto from the University of Pavia and the title of the project is “Integrated Inertial Positioning Systems in Aerial Photogrammetry”.

Since the project has been co-financed by MIUR in 2002 and concerns inertial positioning systems, in synthesis it has been identified as Cofin2002\_IMU. The total cost of the project, which is divided into two annual phases, is 577.000 euros.

Besides the research unit in Pavia, directed by the project leader, eight more research units from other university centres have joined the project: Milan (Professor Carlo Monti), Como (Professor Fernando Sansò), Turin (Professor Sergio Dequal), Vercelli (Professor Ambrogio Manzino), Parma (Professor Gianfranco Forlani), Sassari (Professor Maurizio Minchilli), Palermo (Professor Benedetto Villa), Perugia (Professor Fabio Radicioni). These university centres are spread over all of Italy and this fact plays an important role for the goals of the project.

### **3. Scientific bases of Cofin2002\_IMU project**

In order to evaluate properly a research project, MIUR needs to know the scientific bases, both national and international, which can provide an assessment regarding the improvements the project provides as regards the “state of the art”.

In this project the provided datum-points are the following:

- the research developed in the university centre of Calgary, supervised by Professor Schwarz, who devoted his study both to airborne navigation and to earth navigation;
- the research activity held in the University of Stuttgart, mainly by Michael Cramer, regarding aerial-photogrammetry usage of integrated inertial positioning;
- the test managed by EuroSDR (formerly OEEPE) which has been chosen as the main reference point of the current work thanks to its comprehensiveness, its in-depth research activity and the number of participating units.

Professor Forlani, who is in charge of one of the research units which joined this project, has taken part, as the Italian representative, in the OEEPE test; the test has also been monitored by Professor Galetto, scientific co-ordinator of the project, because of his role as the Italian appointed representative at EuroSDR.

### **4. Goals of the research Project**

The results shown by the OEEPE test have been taken into careful consideration in order to define the objectives of the program, and to define and perform the Italian test according to and in accordance with the guidelines of the OEEPE one. The affinity concerns the fundamental methodology which has been followed, i.e. the use of polygons, each of which has many ground checks measured via GPS. The continuity between the two projects is assured by the fact that for this project the results of the OEEPE test have been chosen as a starting point and its further aims are to widen the sampling and to solve problems which have not been tackled in the European one, such as the possibility to reduce the residual parallaxes locally, the development of intrinsic methodologies in order to control the quality of the results and the drawing up of a series of rules for the planning and testing of the GPS/IMU assisted photogrammetric flights.

On the other hand there are also differences between the two projects. First of all the data examined in our test will consider at least two polygons and they will be marked by a broader range of heterogeneity: for instance cameras with 150 – 300 mm focal length will be used. Besides that, several photogrammetric scales will be taken into consideration, chosen from those more commonly used in Italy for large and medium scale surveys, 1:5000, 1:8000, 1:13000.

Finally, both artificial and natural ground points will be used as photogrammetric control points. Artificial ones obviously obtain a better collimation and an enhanced accuracy, which on the other hand is not realistic, that is to say that it is not comparable to that which can be obtained by common cartographic production. The utilisation of natural points allows for more realistic estimations of the accuracy level of the direct photogrammetric process in its industrial application.

In order to reach its objectives, the project has been divided into two phases, each one lasting one year and based on a different data set.

#### **4.1. Objectives of the first year of research (2003)**

- Study of the quality of the external orientation of photograms obtained in an industrial environment: it is about the quantification of the residual parallaxes and the accuracy of the plotted points.
- Preparation of a test-site, execution of test-flights, distribution of the material to the various units as described in section 6 and further.

#### **4.2. Objectives of the second year of research (2004)**

- Determination of the accuracy and stability in a prolonged period of the GPS/IMU system calibration parameters.
- Individuation of suitable methodologies to eliminate residual parallaxes without resorting to airborne triangulation.
- Individuation of intrinsic methodologies in order to check the reliability of GPS/IMU data, without resorting to airborne triangulation.

- Analysis of the main commercial photogrammetry software in order to check their functionality related to GPS/IMU data.
- Drawing up guidelines for the execution and the testing of airborne photogrammetrical shooting using GPS/INS instruments.

## **5. Study of the quality of the orientations obtained in an industrial context**

In order to accomplish this phase, we wanted to create a vast sample and, besides that, carry out a systematic review. In order to get statistically meaningful results, it has been necessary to collect a great amount of data and in this area the aid provided by “Compagnia Generale Ripresearee-GCR”, which is the most important Italian company working in the field of airborne photogrammetry, has been fundamental.

Because of the over twenty year long collaboration between our University department and CGR, several technicians from CGR have joined the research unit in Pavia and so CGR plays a fundamental role in carrying out the project.

### **5.1. CGR “TerraItaly-City” program**

CGR has performed, from 2000 to-date, a relevant aerial shooting project, carrying out the realization of a program of digital orthophotos called “TerraItaly-City”.

This program consisted in the realization of the photographic coverage of the 110 most important Italian towns, according to their urban extent and resident population, and in the realization of the related digital orthophotos at a nominal scale of 1:2000.

For the aerial shooting, 300 mm focus cameras were used, on which an integrated sensor Applanix POS/AV 510 was installed. The average scale of the photograms is 1:9000 and the related average height is about 2700 m. The photograms have been converted into a digital layout using a Zeiss SCAI scanner, with a resolution of 14µm, corresponding to a 13-centimetre GSD.

CGR has been asked to provide the research units with the images and the Applanix data taken from the “TerraItaly-City” project related to the nine cities of the universities which the research units belong to.

In this way it has been possible to obtain a very meaningful sample of the whole composed of the 110 towns mentioned above, since the nine towns where the research units are based, are spread across all Italy and, in addition, the choice of these nine towns has been completely accidental. It is permissible, therefore, to extend to the whole of the 110 towns which belong to “TerraItaly-City” project the results of the study done on the nine towns which have been chosen.

It should be underlined also that CGR has operated, in realizing the “TerraItaly-City” project, using its standard working protocols. Because of this, the abundance of the material provided and the means by which it has been acquired allow us to extrapolate from the results guidelines which can state execution modalities and accuracies that can be obtained only from the application of IMU technology.

It has been decided to provide every research unit with a set of 8 x 3 photograms and two external orientation sets: the ones acquired through a direct sensor orientation process (APP) and the ones obtained with a type of integrated sensor orientation (AAT), calculating an airborne triangulation whose observations only consist in photogram external orientation and the image coordinates of tie points, automatically measured.

The research units have been asked to:

- measure on the ground at least 50 landmarks with GPS or topography,
- observe the landmarks on all the photograms,
- observe at least 9 tie points on each model.

The units have not been asked to stereoplot the points only, but to memorize the image coordinates of all the observed points, so that it will be possible to manage a wide range of different elaborations.

First of all, a systematic study on residual parallaxes has been performed. A specially conceived SW by Pavia university’s pilot unit considers, for each tie point, all the models in which it can be seen, stereoplots it and makes an estimation of the residual parallax in the object space, measuring it as the distance between the homologous straight lines.

The control points have also been controlled comparing their coordinates as determined by photogrammetry with those provided by the GPS system.

The approach we chose allows for the application of different external orientation systems to the image coordinates, by simply changing a line of code. Controls have been performed using APP and AAT data and also using external orientations calculated in other ways, for instance with a classical AT.

A very detailed protocol has been defined in order to format and exchange the various data, so that the data produced by each unit can be processed using the programs prepared by Pavia University, in order to allow an optimal comparability among them.

The first results of this phase are already available and they concern only a few units. By October 2003 all the units should finish this phase and publicize their results. We stress once more that the main interest of this phase consists in a very broad sampling (9 flights randomly chosen among 110) and in the fact that the examined flights have been performed in an industrial production context. It has been decided to have them checked by the researchers only after their acquisition and orientation.

## 6. The Pavia's test site: pre-existing features

The 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. We won't fully describe them all in this paper, but we will focus principally on those which are significant for the Project under description.

### 6.1. 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.

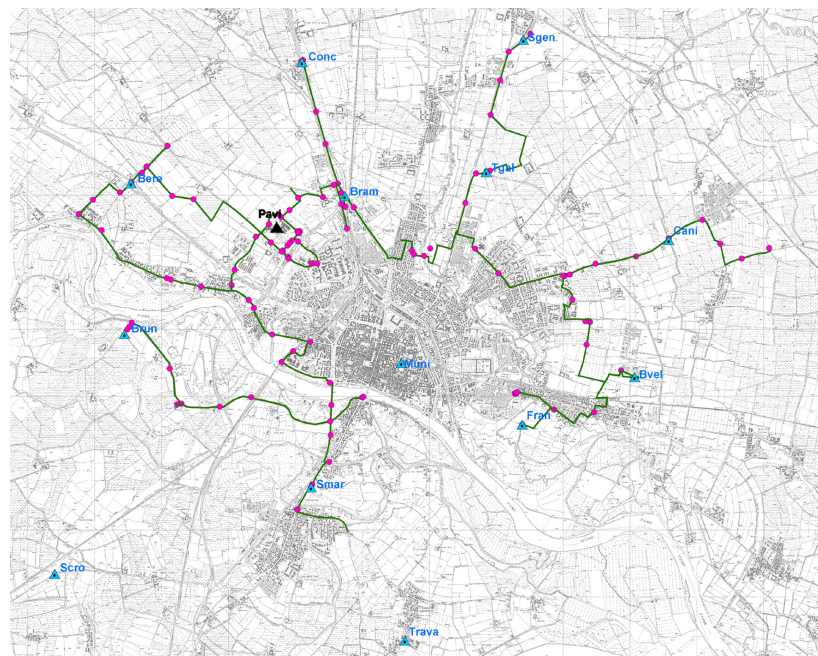


Figure 1: Pavia's GPS and levelling networks. Blue triangles are the GPS network vertices, red circles represent levelling benchmarks, green lines are levelling paths. The black triangle represents the GPS permanent reference station.

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.

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

Table 1: mean statistical parameters of standard deviations  $\sigma$  of the network vertices, referred to a local Cartesian coordinate system, measured in centimeters.

The greater part of the network's points have been connected by geometric leveling, 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.

## 6.2. 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	Type of support	Covered area	Owner	Year of production/last update
1:500	Paper and raster	Downtown	Pavia city	1984
1:2000	Paper and vector	The whole city territory	Pavia city	1982/2000
1:10000	Paper and raster	The whole regional territory	The Lombardia region	1983/1994

Table 2: main characteristics of the available cartographies concerning Pavia.

Morover we have a colour ortophoto 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.

## 6.3. Other things

Pavia's test site has some other interesting features. We have several lidar datasets and many check measurements for lidar data: they are 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.

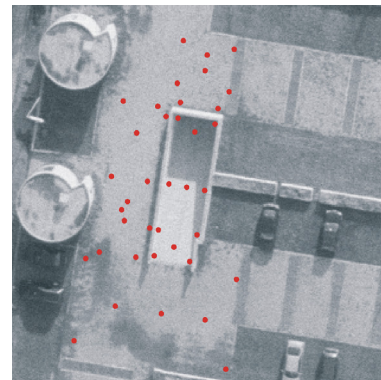


Figure 3: example of a check area constituted by a ramp.

## 7. Features which have recently been added due to the Project

Some features have been created from scratch, to fully support the execution of the Project. They are mainly Artificial Ground Control Points, AGCP, and Natural Ground Control Points, NGCP, two sets of points whose coordinates are known and have been measured with high precision.

## 7.1. The AGCPs set

A 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. Preliminarily to the creation of the complete set of markers, we have 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. The 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.

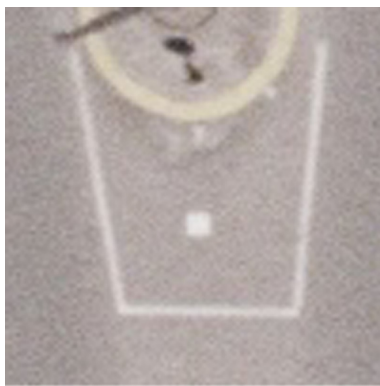


Figure 9: visibility of the PV\_AGCP\_100 marker on a 1:5000 image.

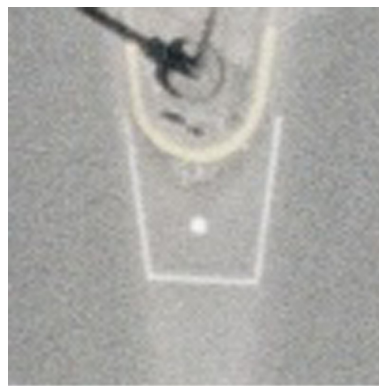


Figure 10: visibility on a 1:8000 image.



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.

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

Table 3: mean statistical parameters of standard deviations  $\sigma$  of the 169 AGCPs, referred to a local Cartesian coordinate system, measured in centimeters.

In order to point out and eliminate set-up gross errors, all the AGCPs will be re-measured next autumn, with a lower redundancy. It is our intention to keep our test site efficient. This has already required, and will require in the future, brushing the markers regularly and repainting those which have lost their colour. Furthermore, we have already had to substitute mobile markers which have been stolen.

## 7.2. 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 of the PV\_NGCP\_403 marker 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 the Table 3 shows.

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

Table 4: mean statistical parameters of standard deviations  $\sigma$  of the 62 NGCPs, referred to a local Cartesian coordinate system, measured in centimeters.

NGCPs will also be re-measured, next autumn, to filter out set-up gross errors. The AGCPs set is fully complete, but we intend to enrich the NGCPs set by adding further control points.



## 8. 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 have the same structure, shown in Figure 16, Figure 17 and Figure 18, are composed of three blocks. 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 across-track overlapping is 60%, as well as the across-track. The images' number 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.

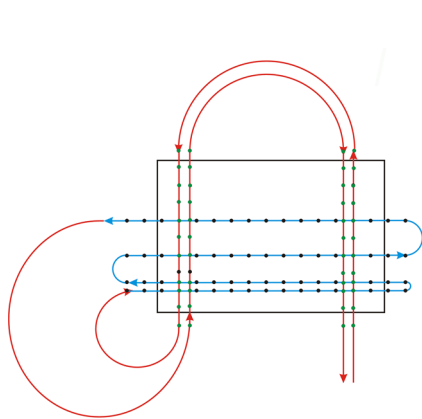


Figure 16: structure of the 1:5000 block.

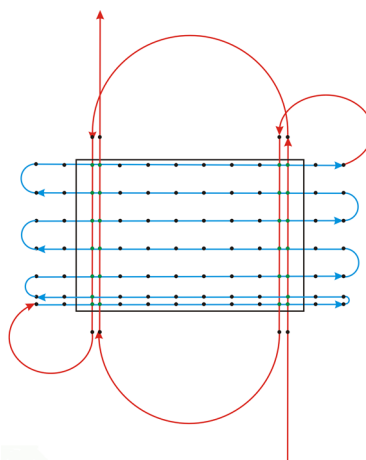


Figure 17: structure of the 1:8000 block.

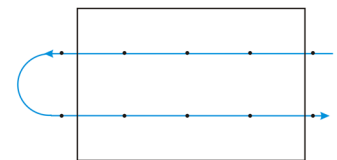


Figure 18: structure of the 1:18000 block.

**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 1:18000 blocks, having the structure described above. **Flight 4** is composed only of the 1:8000 block.

Flight	Date	Scale	Date	Focal length	Relative flight height	Overlappings	Stripes 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.

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. Figure 19 summarizes the geometry of the various flights.

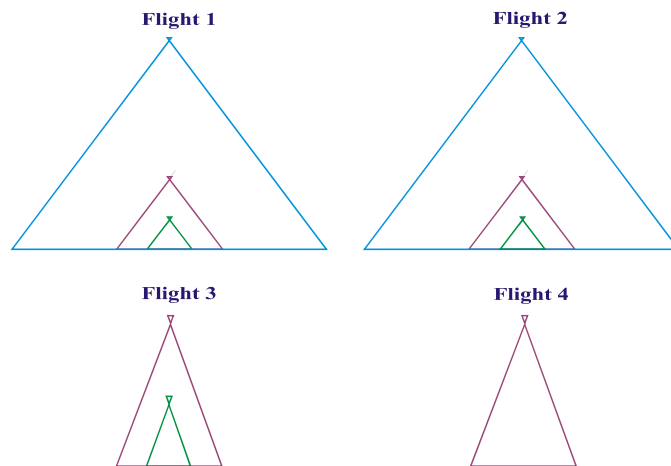


Figure 19: graphical summary of the flights.

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.

## 9. 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.

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