GPS AND PHOTOGRAMMETRY: AN ITALIAN EXPERIMENT

Astori B., Pinto L.

Dipartimento I.I.A.R. - Politecnico di Milano
Piazza Leonardo da Vinci 32
20133 Milano - ITALY

Commission I

ABSTRACT

This paper outlines the photogrammetric experiment with GPS equipment carried out in Italy by a research group of the Politecnico di Milano. It presents the project and the execution of three experiments, two of which with aerial photo takings - including positioning of the ground control points with GPS methods - and it analyzises the obtained results. GPS data processing has been performed by carrier phase measurement reduction methodology and by methods employing pseudorange measurements for the integer phase ambiguity solution - phase smoothed pseudorange and phase dynamic model -. These last methods have the advantage of being less sensitive to cycle slips. The accuracies obtained by comparing the aerial triangulation results, confirm the high accuracy of GPS position system. Accuracies suitable for the ground control of blocks adjustments for medium-small maps have been obtained by using pseudorange measurements.

KEY WORDS: Photogrammetry, GPS, Accuracy, Survey, Mapping.

1. INTRODUCTION

In the last years the use of GPS system in aerial photogrammetry has increased either for navigation purposes and as support for aerial triangulation. Waiting for the Defence Department of United States to guarantee the continuity of service and the completion of the spatial segment of the GPS system, in Italy we are making some experiments with the following three finalities:

a) technical-operational achievability of the insertion of a receiver and GPS antenna on an aircraft for photogrammetry;

b) verification of the accuracy of kinematic GPS positioning in highly dynamic conditions;

c) adaptability of GPS accuracy to aerotriangulation for medium and large scale maps (Ackermann, 1986).

In the beginning of April 1991, in Italy, the first flight was made with an on board GPS receiver. We carried out different experiments, some of them associated with aerial photogrammetry recordings. The experiments have been carried out by D.I.I.A.R. of the Politecnico di Milano in collaboration with the Compagnia Generale Ripreseaeree of Parma for the aerial photogrammetric part and with Geotop of Ancona for the GPS part. The research has been developped in three subsequent steps, as will be explained later by quoting the obtained results:

1) June 1991: photogrammetric flight over a testfield in Parma;

2) December 1991: photogrammetric flight over a network in Lucera (Foggia);

3) March 1992: flight tests in Parma.

2. PARMA, JUNE 1991: FIRST EXPERIMENT

2.1 Project and test flight

The first Italian photogrammetric photo flight experiment associated with a kinematic GPS survey was carried out in June 1991 (Astori, 1992). The purpose of this experiment was testing the relyability of the method from the technical and operative point of view and supplying the first indications on the accuracy of the kinematic GPS positioning.

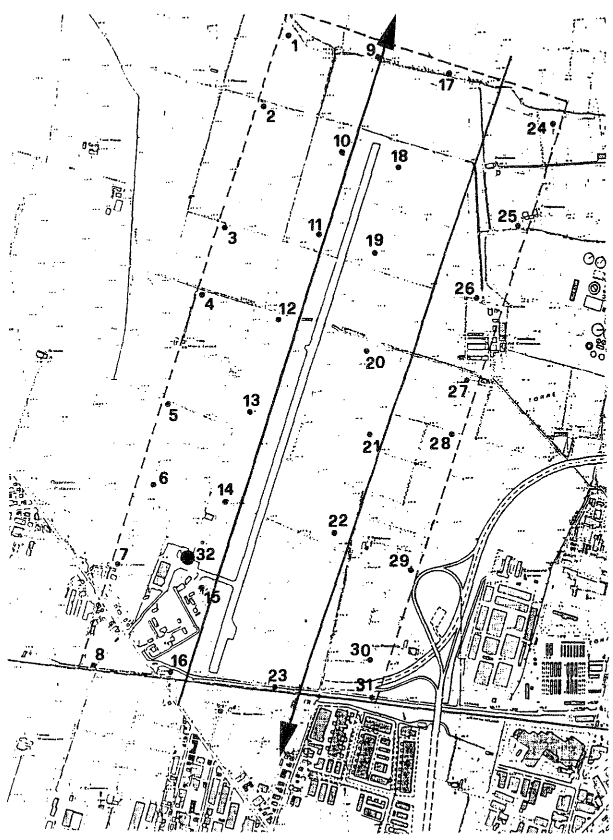


Figure 2.1 - Parma experiment: testfield configuration and photogrammetric project.

A testfield of 32 signalized ground control points has been realized on a surface of 2.4 X 1.2 km^2 in the neighbourhood of the civil airport of Parma. The points, set on 4 rows longitudinal to the axis of the runway (figure 2.1), have been surveyed with kinematic GPS methodology in Stop and Go modality. The measurements have been repeated twice and some distances have been verified by classical surveying using an electronic distance measurement device. The verified accuracies, either in terms of repeatability or measures reliability, are of about 1 centimeter thus, suitable for aerotriangulation for large scale maps (Pinto, 1992).

The photogrammetric project (figure 2.1) forsaw a flying height above ground of 500 m by using a wide angle camera with a focal length of 150 mm; the resulting image scale equals 1:3300. The covering of the testfield is completed in two parallel flight strips with a 60% side overlap. The forward overlap was fixed in 80%. The photogrammetric equipment consisted in a WILD RC 20 photogrammetric camera provided with a FMC magazine; the aircraft was an Aermacchi AL 60 with a cruising speed of 180 km per hour.

Two Ashtech M-XII GPS receivers capable of performing both C/A code pseudorange and L1 carrier phase measurements were used; the first fixed on the origin of the local reference of the testfield on the point 32 (figure 2.1), the second on the aircraft, provided with a kinematic antenna and linked to the photogrammetric camera. The link between GPS antenna and photogrammetric camera was planned and carried out in two ways (figure 2.2).
a) Geometric link. We directly measured - with plumb-line and level - the offset between the GPS antenna mechanic center - considering the offset between antenna phase center and antenna mechanic center - and the camera principal point, in the image plane, set in horizontal attitude. To this vector we have added the segment linking the principal point with the entrance pupil center cone along optical axis direction.

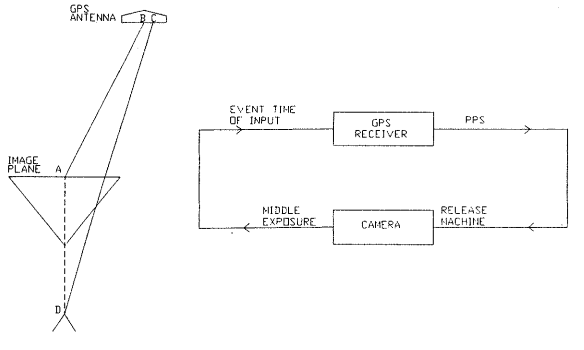


Figure 2.2 - Geometric and temporal link between the GPS equipment and photogrammetric camera.

b) Temporal link. This was carried out by using a loop between camera and GPS receiver which is able to perform:

1) the shutter input to the camera by the GPS receiver thanks a pps signal (pulse per second) synchronized at the GPS time;

2) to GPS receiver through the exact shutter release time, available in output from the same camera.

On the 9th and 10th of June 1991, after a series of flights to test the equipment and the hardware links, we have carried out two flights with several aerial photos taking. The two planned flight profiles were covered several times for a total of 6 strips - No. 1, 2, 3 strip on the 9th of June, No. 4, 5, 6 on the 10th of June -. The initial phase integer ambiguity measurement was computed using a precise baseline determination by a stationary phase observation between a known reference point and the aircraft for about 30' : for the first day only at the end of the flight, for the second day both before the takeoff and after the landing. In both flights (figure 2.3) we have verified a disconnection of the carrier phase signal, during a turn in two of the five linked satellites. The satellite constellation in both days included five satellites - No. 2, 6, 12, 13, 23 - with a PDOP lower than 5. Figure 2.3 shows the graphics of the two fligts projected on a horizontal plan.

2.2 Aerial triangulation and GPS data processing

Aerotriangulation, having the purposes of determining the tridimensional position of the camera projection center of each photo, was carried out connecting the 6 strips and including a total of 79 photos. The CALGE bundle adjustment program of Politecnico di Milano was used for the block adjustment. For each photo, the program has estimated the camera projection center coordinates and their standard deviations. The r.m.s. of the standard deviations in the three coordinates are the following:

$$\begin{aligned} rms(StD)\ X &= 6.4 \text{ cm} \\ rms(StD)\ Y &= 6.2 \text{ cm} \\ rms(StD)\ Z &= 2.3 \text{ cm} \end{aligned}$$

The reference system is a local cartesian with origin in the point No. 32. The ground control points coordinates, obtained in the WGS '84 system, were therefore transformed to the mentioned local system.

GPS data processing was performed in kinematic mode between the GPS receiver set on the aircraft and the one in stationary position on the known reference point 32. We have analized both the solution obtained from the carrier phase reductions, starting from the initial phase ambiguity computed with a specific measurement session, and the solution performing the initial phase ambiguity, computed during the flight by using the pseudorange measurement - phase smoothed pseudorange and phase dynamic model - (Ashkenazi, 1990).

In relation with the solution of the carrier phase reduction it is important to underline that because of the cycle slips occured in the two different flights, we could not process the flights starting from a single measurement of phase integer ambiguity. However, the 10th of June flight was totally determined in the center phase positioning of GPS

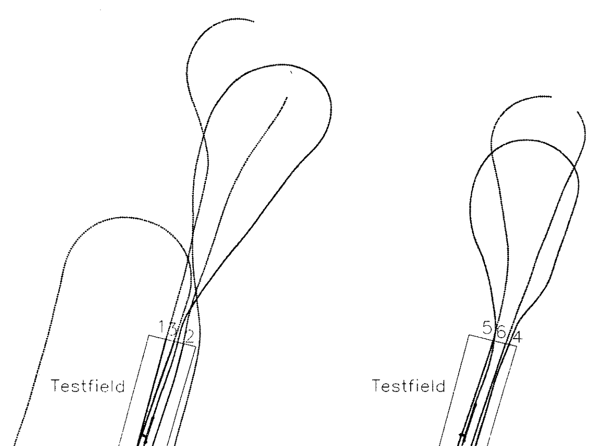


Figure 2.3 - Parma experiment: flight path of 9th June 1991 (strip No. 1, 2, 3) and of 10th June 1991 (strip No. 4, 5, 6) with cycle slips.

antenna because the phase ambiguity was computed both at the takeoff and after landing. Instead with 9th of June flight we missed the first part concerning the first strip, because computation of the integer ambiguity was performed succesfully only at the landing. In conclusion the carrier phase reduction was fulfilled only in 5 of the 6 flight strips: No. 2, 3, 4, 5, 6.

For the carrier phase data processing we have used the GPPS program of Ashtech, which has given the center phase position of the GPS antenna for every second, being this the observation rate used. - To determine the phase center position of the GPS antenna with kinematic methods using pseudorange measurement, we have used the same data of the carrier phase reductions. The calculation algorithm has determined the unknown phase ambiguity when needed - after the cycle slips - by using the pseudorange measurements duly weighted - phase smoothed pseudorange - or dynamic models which employ the velocity vector - phase dynamic model -. For this purpose we have used two different computational programmes:

PPDIFF of Ashtech;

TOPAS of the University of Munich (Germany) which, in comparison with the previous one, uses optimising with a Kalman like filter.

In the last case, the GPS data processing provides the antenna phase center position for the whole flight - also of the first strip - except for the two flight sides in which the number of linked satellites was less than 4.

Moreover, for each data processing, we have determined the camera projection center position modelling the flight path by using a linear interpolation in time between two GPS contiguous positions and taking out the offset GPS antenna measured on the ground and rotated of the photos attitude. The trajectory mathematical model was efficient by a linear interpolation rather than, for instance, a spline interpolation. This has occured because the delay between the GPS positioning time and the shutter release time, thanks to the link between GPS receiver and camera, was always in the order of 1/10 of second. Finally the resuls have been transformed into the same reference cartesian local system adopted for aerial triangulation block adjustment.

2.3 Analysis of the results

Of the projection center positions of 67 photos of the 5 strips - No. 2, 3, 4, 5, 6 - processed by carrier phase reduction and of those of 79 photos of the 6 strips processed by pseudorange measurement methods, we have determined the differences Dx, Dy, Dz, of the projection center coordinates computed by GPS and by aerotriangulation (A.T.).

Table 2.1 shows the summarized values in terms of root-mean-square value of the average of differences per strip rms(MDiff X, Y, Z) and of the standard deviations of the differences rms(StD Diff X, Y, Z) for each of the three tests. Analyzing the table 2.1 shows that the rms of the differences averages in test 1 is meaningful for Z coordinate only: such a systematic error has been studied for a long time however we could not find a real physical explanation.

In relation to tests No. 2 and 3 the rms of the differences averages is little meaningful because the value are dispersed. This is mainly due to the fact that the determination of the unknown integer phase ambiguity by using pseudorange measurements, after every cycle slip, creates a systematic error in the positioning which increases linearly in time (Friess, 1990).

TEST		rms M Diff [m]	rms SD Diff [m]
1	X	0.04	0.05
Phase	Y	0.06	0.07
redution	Z	0.53	0.03
2	X	0.66	0.17
PPDIFF	Y	2.71	0.25
ASHTECH	Z	3.53	0.54
3	X	12.42	0.07
TOPAS	Y	2.36	0.10
dynamic model	Z	3.95	0.20

Table 2.1 - Parma experiment: rms of averages (M Diff) and of standard deviations (SD Diff) of the differences between the projection center coordinates determined by GPS and those determined by A.T..

The values concerning the rms of the standard deviations of differences are undoubtedly very interesting because they define the very accuracy of kinematic GPS positioning in relation to the one of the photogrammetric block adjustment. In test 1, concerning the strictest GPS positioning methodology, the very small values in all three coordinates, confirm the high potential accuracy of kinematic GPS; with reference to the planimetry you can see a degradation in the Y coordinate accuracy rather than in X coordinate in all the three tests. This is probably due to the simplified modelling of the flight path - linear interpolation between the two GPS contiguous positions with 1 second recording - being the principle flight direction oriented along Y axis (figure 2.3).

Besides, for the three coordinates differences of each strip, we have computed the linear regression lines; this operation finds its explanation in the single differences analysis, for each photo, which shows, for tests 2 and 3 above all, a clear systematic effect depending upon time. This phenomenon, interpreted as a linear drift, finds large confirmation in literature (Friess, 1988; Ackermann, 1988) and as above mentioned, it can be ascribed to a wrong imposition of initial phase ambiguity during the calculation. The calculated drift, however, does not remain constant during the flight but assumes a different value and sign with the changing of the considered strip.

The testfield is very small, and therefore the time of photo taking is only 40 seconds for each strip. This makes a complete drift analysis difficult, especially for long periods,

TEST		rms M Diff [m]	rms SD Diff [m]
1	X	-	0.05
Phase	Y	-	0.06
redution	Z	-	0.03
2	X	-	0.10
PPDIFF	Y	-	0.18
ASHTECH	Z	-	0.25
3	X	-	0.05
TOPAS	Y	-	0.07
dynamic model	Z	-	0.04

Table 2.2 - Parma experiment: rms of averages (M Diff) and of standard deviations (SD Diff) of the differences between the projection center coordinates determined by GPS and those determined by A.T., after removing linear drift.

and we are not able to explain the reason of an apparent uncorrelation among the different strips. Therefore, avoiding the calculated linear drift effects, we obtain some new differences for the three coordinates of each photo, which we have considered in the three tests; of these differences, having zero average, we can calculate the standard deviations. Table 2.2 shows the root mean square values of the standard deviations of the differences for the three coordinates: rms(StD Diff X, Y, Z). The values are of great interest from a photogrammetric point of view because they provide an accuracy parameter of how GPS system is able to determine the projection center coordinates by using different calculations methods - which correspond to different technical operative modalities -. A worsening of the accuracy along the flight direction for the three tests is still evident.

With reference to the processings which combine carrier phase and pseudorange measurements instead, the dynamic model with Kalman filter, - used by the TOPAS program - provides better results than the phase smoothed pseudorange of Ppdiff; in the first case even compared with the solution obtained with carrier phase reduction.

At the end of this analysis of experimental results, we need to take into consideration that both flights have been carried out making the aircraft attitude be as good as possible horizontal during the turns. This minimizes the cycle slips, which generally are caused by the satellite shadowing because of the aircraft wings.

A more realistic photogrammetric flight simulation should consider aircraft attitude variations of 10°-20°, which increase the probability of cycle slips and consequent impossibility to achieve the optimal solution by carrier phase reductions. This is the reason why 2 and 3 tests results have great importance. Infact, it is important to remind that they have been obtained without considering the phase ambiguity calculation effected before the takeoff and after the landing by a stationary phase observations between a known reference point and the aircraft.

3. LUCERA DECEMBER 1991: SECOND EXPERIMENT

3.1 Project and test flight

In December 1991 we have planned and carried out a second experiment of a photo flight combined with a kinematic GPS survey. The principle purpose of this experiment was:

a) to confirm the accuracies obtained in the previous experiment;

b) to verify the functionality of the equipment and of the relative links;

c) to provide elements of study linked to the fitting of a photogrammetric block to a pre-existent known control network - and thus subject to a reference system transformation;

d) to analyze the drift of the GPS, made possible because of the large testfield size.

The testfield in Lucera (Foggia) (Crespi, 1991) with dimensions of 12 X 9 km^2 contains a network of 181 ground control points, to which about 400 known photographic control points are connected (figure 3.1). Before performing the flight photogrammetric project a photogrammetric block simulation has been carried out in order to investigate the best flying height above ground in relation with the control points treedimensional accuracy and the side and forward overlap chosen in project.

The simulated block adjustment evidenced an optimal flying height of 1500 meters for the WILD RC20 aerial camera. This corresponds to an image scale of 1:10000. The side overlap of 60% has allowed to take a testfield area about 4 km long, with 4 strips; the forward overlap was 80%.

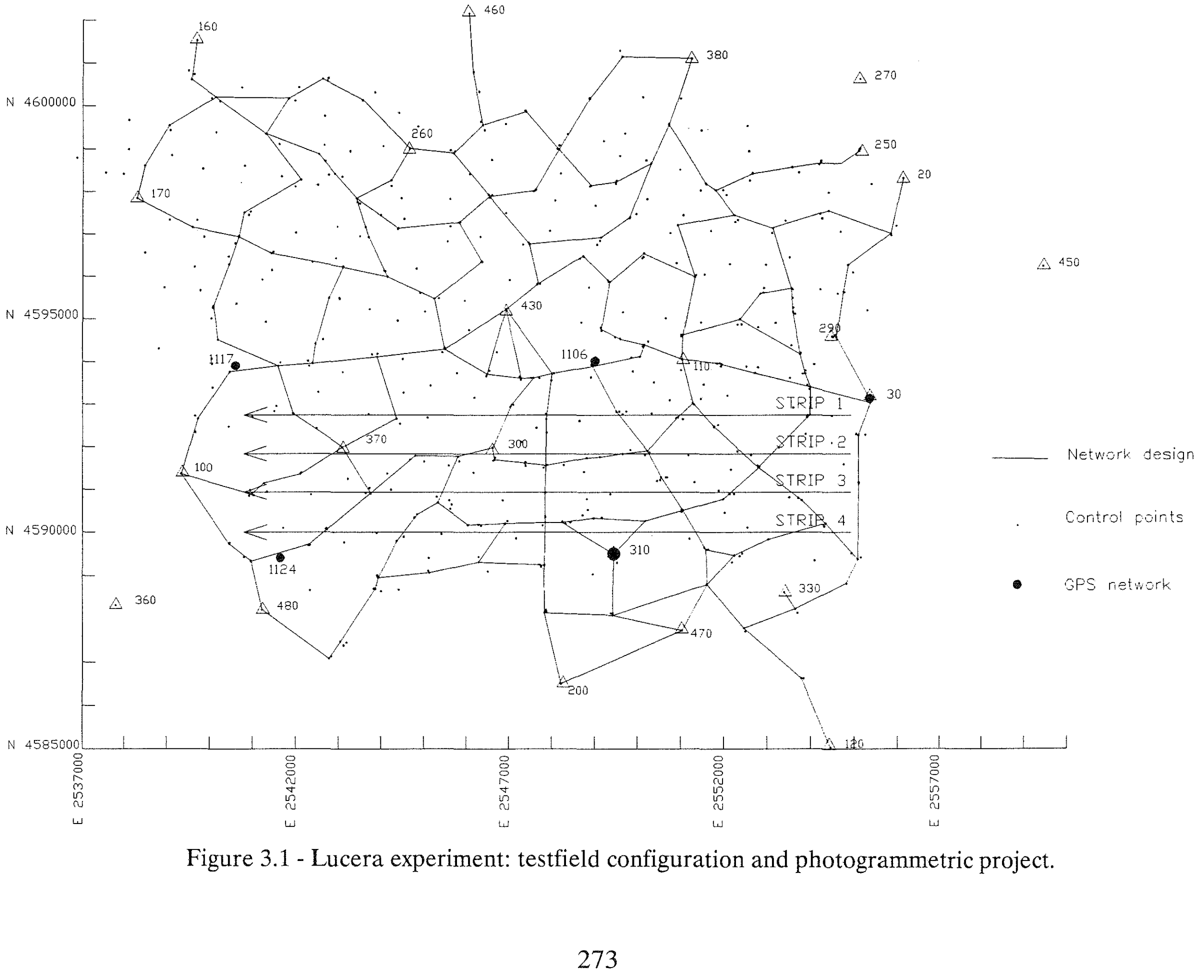


Figure 3.1 - Lucera experiment: testfield configuration and photogrammetric project.

Survey operations of 5 ground reference points with GPS equipment (figure 3.1) were of geat improtance: they were used to determine the transformation parameters between the local reference cartesian system, in which the network adjustment was carried out, and the WGS 84 reference system. The 5 ground reference points have been determined by 10 independent baseline adjustments, measured by stationary phase GPS observations. The seven spatial transformation parameters of a similarity transformation have been determined by a least squares adjustment program which has also provided the standard deviation of transformation parameters, as below:

StD DX = 9.8 mm StDΩ = 1.4 cc
StD DY = 9.8 mm StDΦ = 2.7 cc
StD DZ = 14.4 mm StD K = 1.4 cc
$\lambda = 7.9\ 10^{-6}$

The maximum point coordinate difference after the transformation is 3.1 cm (Z coordinate of point 106). For these assumptions the adopted reference system is of local cartesian type with origin in known point 310. The photogrammetric equipment is the same as in the previous paragraph. Also in this case we have used two Ashtech M-XII GPS receiver, the first fixed in the known coordinates point, the second, set on the aircraft linked to a kinematic antenna; the observation rate measurement has been taken, also in this case, equal to one second.

In relation to the temporal link between the aerial photogrammetric camera and the GPS receiver, in this experiment, we only obtained the output of the camera, in correspondence with its shutter release time, because of a breakage which has not allowed the management of the camera shutter directly by GPS receiver PPS. This has surely brought an accuracy degradation along the flight profile - X axis direction - above all having adopted a trajectory linear model, among the GPS phase centers.

Two flights have been carried out: the first on 16th December 1991 and the second the following day. During the first flight (figure 3.2) the four planned flight profiles have been carried out, however a series of cycle slips has interrupted the satellite link many times. Unfortunately, during the flight of the following day, two cycle slips, occured immediately after takeoff and before landing, made the carrier phase reduction processing impossible. In both days the used satellite constellation included 5 satellites (13, 14, 18, 19, 24) with a PDOP of 5; the temporal width of the satellite constellation has imposed at the flight time to be contained within 90 minutes.

3.2 Aerial triangulation and GPS data processing

During the two flights about 350 photos in 4+2 flight profiles, two of which overlapped, have been carried out. So far the aerial triangulation has been performed upon two strips - the No. 3 and the No. 4 of 16th December 1991 - with 60% forward overlap for a total of 38 photos. Bundle adjustment by CALGE was carried out, in order to obtain the projection center coordinates and their standard deviations. Rms values for the standard deviations values for the three coordinates are as below:

rms(StD)X = 18.3 cm
rms(StD)Y = 19.1 cm
rms(StD)Z = 14.7 cm

GPS data have been processed with kinematic methodology between the known control point 310 and the moving point on the aircraft. Because of cycle slips we could not obtain the carrier phase reduction solution, however using the pseudorange observations, we have applied the same already mentioned criteria of the previous paragraph, in the phase smoothed pseudorange and phase dynamic model processing - PPDIFF Ashtech and TOPAS program -.

Also in this case we have used a linear interpolation between the contiguous GPS coordinates to obtain the antenna phase center position at the moment of shutter release; then, taking out the rotated of the photo attitude offset, we have determined the camera projection center position by GPS. Finally, we have transformed the projection center coordinates in order to put it in the already adopted cartesian reference system of the aerial triangulation.

3.3 Analysis of the results

As for the analysis of the results of the Parma experiment of June 1991, for each of the 38 photos belonging to strip No. 3 and No. 4., we have determined the differences, in the three coordinates, between the projection center position obtained with GPS and A.T.

Table 3.1 shows the root mean square of the averages rms(MDiff X, Y, Z) and the root mean square values of the standard deviations rms (StD Diff X, Y, Z) of the differences between the projection center coordinates determined by GPS and those determined by A.T., analyzed strip after strip. As already seen in the previous paragraph, the averages rms value is not very meaningful because of its high entity, therefore very damaged by the systematic errors presence which seem correlated with the time - above all in test No. 2 concerning the phase dynamic model solution of TOPAS program -.

For this reason we have used linear regression line parameters for each coordinate of the considered strips. We have, in this way, deducted the solution, as shown in table 3.2, where it is possible to remark the results improvement in terms of rms of the standard deviations of the differences, this time, at average zero.

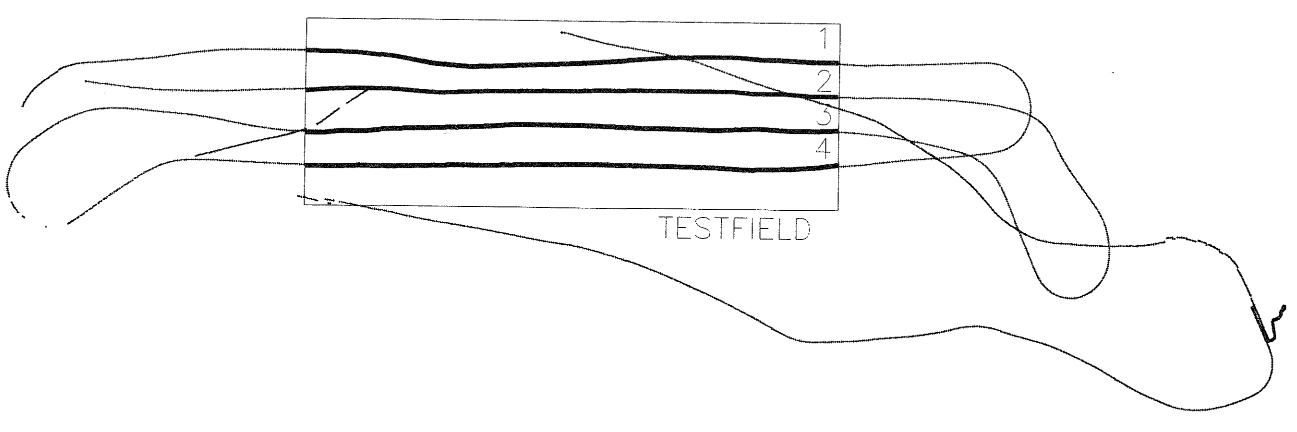


Figure 3.2 - Lucera experiment: flight path of 16th December 1991 with cycle slips.

TEST		rms M Diff [m]	rms SD Diff [m]
2 PPDIFF ASHTECH	X	1.60	0.67
	Y	1.41	0.42
	Z	4.53	1.14
3 TOPAS dynamic model	X	8.70	4.45
	Y	3.61	2.38
	Z	3.33	1.54

Table 3.1 - Lucera experiment: rms of averages (M Diff) and of standard deviations (SD Diff) of the differences between the projection center coordinates determined by GPS and those determined by A.T..

TEST		rms M Diff [m]	rms SD Diff [m]
2 PPDIFF ASHTECH	X	-	0.65
	Y	-	0.39
	Z	-	0.66
3 TOPAS dynamic model	X	-	0.67
	Y	-	0.28
	Z	-	0.58

Table 3.2 - Lucera experiment: rms of averages (M Diff) and of standard deviations (SD Diff) of the differences between the projection center coordinates determined by GPS and those determined by A.T., after removing linear drift.

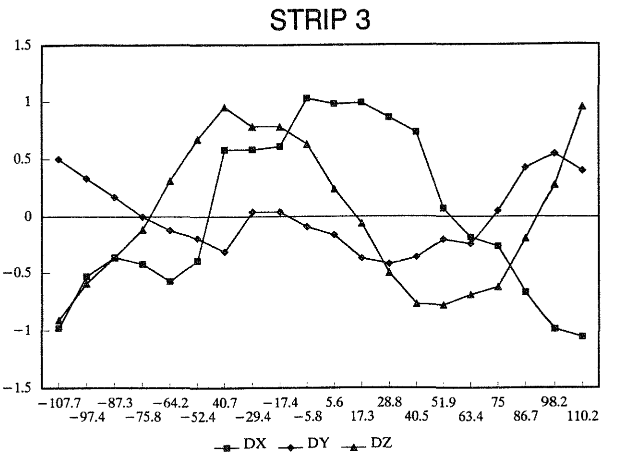
Also for this case, the differences component in the flight direction, that is to say X axis, has inferior accuracy; this is probably due to the too much simplified assumed trajectory model. The temporal length of the considered strips (4') allow to evidence the drift of the GPS solution with respect to the photogrammetric one, which was the aim we wanted to achieve with this experiment.

Figure 3.3 shows DX, DY, DZ differences line graphs for the three coordinates for both strips 3 and 4 - after removing linear drifts -.It is clear - specially for DZ difference - a ripple moving, time dependent. At a first analysis, which will be closely examined in future, we can already deduct that the phenomena amplitude and period are very similar with regard to DX, DY, DZ differences. Therefore, we can consider more suitable, in the individuation and removing of the time dependent systematic effects, to take into consideration a ripple propagation drift - for instance sinusoidal - rather than linear.

The rms of the standard deviation of the differences, as shown in table 3.2, are worth of some further comments; in comparison with the results of Parma experiment, these last have surely an inferior accuracy. In order to explain this an inferior accuracy we can outline two causes at least:

a) the real less accuracy of the photogrammetric block adjustment taken as base for the differences calculation;

b) the presence of many cycle slips - immediately before the strip No. 3 - which affect negatively the accuracy.



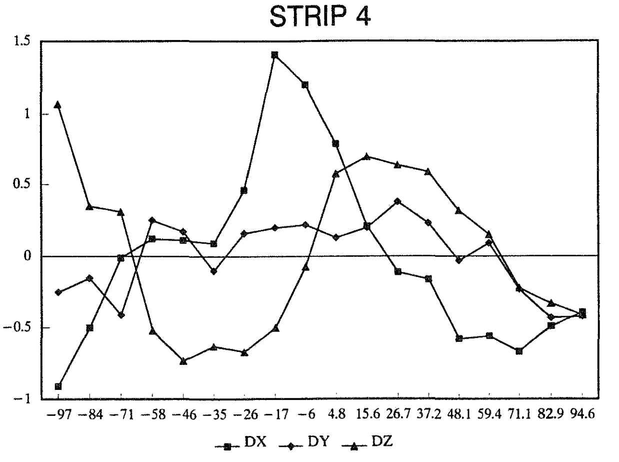


Figure 3.3 - Lucera experiment: line graph of the coordinates differences between GPS and A.T. (DX, DY, DZ) after removing linear drift. (Strip No. 3, 4 - Test No. 3).

4. PARMA MARCH 1992: THIRD EXPERIMENT

During the analysis of the flights carried out in Lucera, the individuation of the causes which have produced the great number of cycle slips has been a big unknown. In March, a flight, without photogrammetric equipment on board, has been carried out in the proximity of Parma airport in order to verify operatively the functionality of the used equipment.

Aircraft, kinematic GPS antenna and its position - figure 4.1 shows the antenna position on aircraft body - were the same of the two previous experiments. A splitter, linked to the antenna preamplifier, has given the same signal to two different GPS receiver: an Ashtech M-XII and a Trimble 4000 SE. Besides, the experiment purpose was to verify the behaviour of two GPS receivers with the changing of the

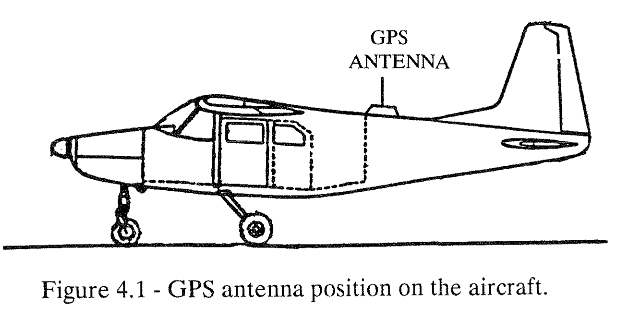


Figure 4.1 - GPS antenna position on the aircraft.

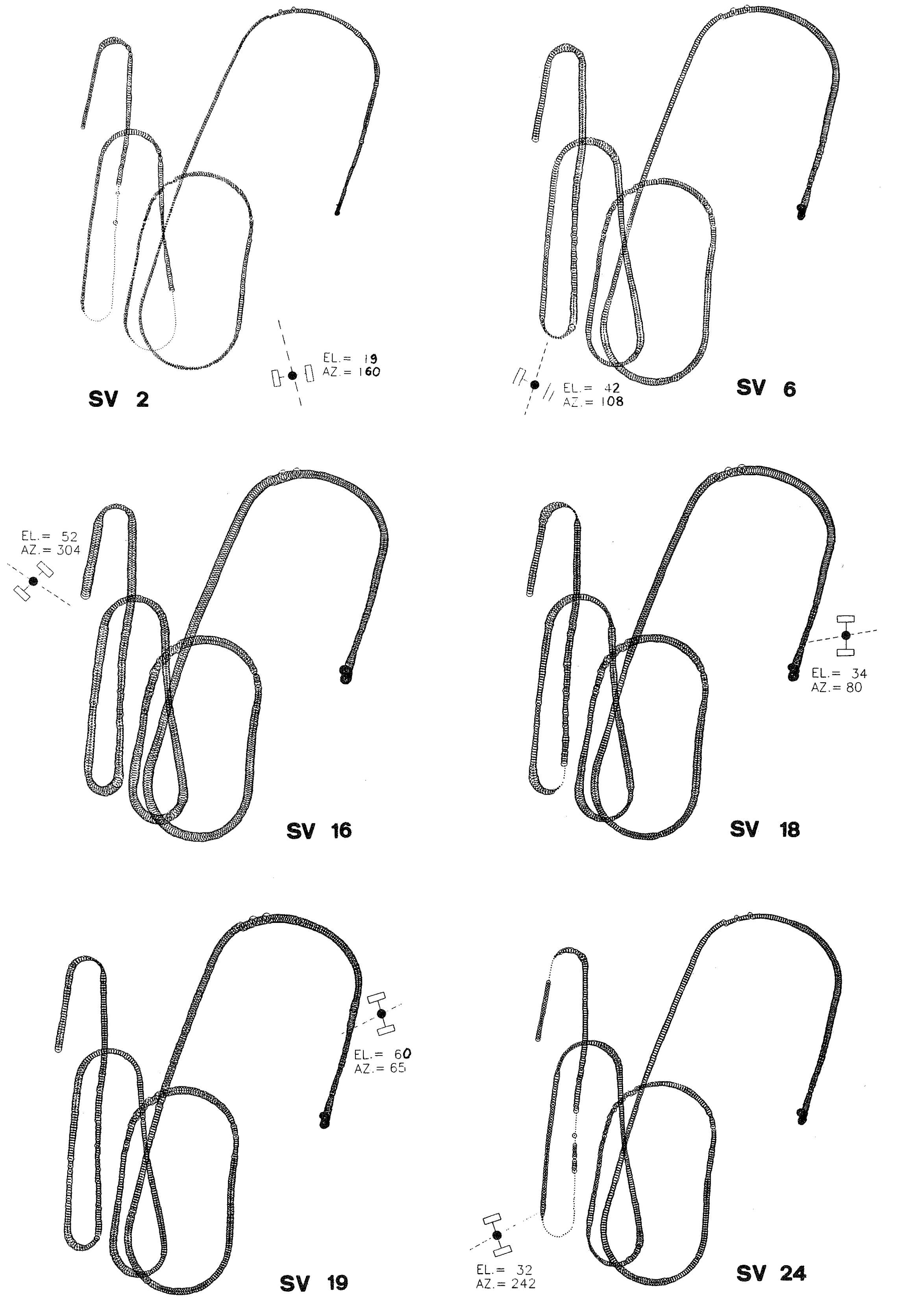


Figure 4.2 - Parma flight test: S/N ratio value during the flight for each satellite (turns at 0°, 20°, 40° tilt). (Ashtech receiver).

aircraft attitude during the flight. Hence, some turns with 0°, 20°, 40° tilt, that is to say even behind the limit which is generally reached by an aircraft during a photo taking, have been carried out at the same time of the strips series simulation.

The experiment has been carried out 27th June 1992 and the satellite constellation included the following 6 satellites: 2, 6, 16, 18, 19, 24; PDOP was inferior to 5. The results analysis has been carried out with regard to the signal/noise ratio value (S/N) for each satellites during the flight.

At the moment we are not able to give compared results for the two GPS receivers, however we can show the results with regard to Ashtech GPS receiver. Figure 4.2 shows the results plots, divided in satellites; the S/N ratio value has been represented by a circle with radius proportional to the ratio. The aircraft position has been deducted from the one recorded in real time by GPS receiver and computed starting from pseudorange values measured with accuracy of 30 m: for this reason, in the plot some anomalous trajectory deviations are present.

Following the aircraft path in the plot, starting from takeoff a first semiturn with 0° tilt has been carried out in order to reach the experiment area; moreover, always following the aircraft path in the plot, two semiturns at 0° tilt, two at 20° and two at 40° tilt are recognizable. Where the circle is inexistent but the only point representing the position is there, it means that the satellite has had a cycle slip in that point.

At conclusion of this flight analysis, we can say that the presence of cycle slips is mainly due to geometric causes linked to the antenna positioning, set on the aircraft body, in relation with the linked satellites elevation; on the contrary of what previously thought after Lucera failures, causes due to the inadequate responding of GPS receiver when radial accelerations arise during the turns, are to be excluded.

5. CONCLUSIONS

At the end of this series of experiments, performed in a year by the research group of the Politecnico di Milano - in the field of GPS applications to aerial photogrammetry - we can state that the GPS system will be, in a near future, a great sustain to the aerial triangulation thanks to its capacity of giving the projection center positions.

However, in this moment it is important that block adjustment programs are modified to be able to have, as additional constraints, some pseudo-observation equations which consider the projection center obtained by GPS. Besides, we need to consider the opportunity of modelling the GPS solution drift with ripple functions, when long strips are carried out. The trajectory modelling to interpolate the projection center position between two contiguous GPS positions can produce errors in the flight direction; for this reason the shutter release needs to be as near as possible to the GPS positioning time. Nevertheless, the linear interpolation is not always suitable; sometimes a spline interpolation can give better results.

The found accuracies, in terms of projection center coordinates differences - between GPS and A.T. solution - put in evidence a use of the positioning data - in case it is possible to use the carrier phase reduction processing - suitable to the medium-large scale mapping (1:5000 - 1:2000). On the contrary, when it is necessary to use the pseudorange measurements - for the positioning resolution - with an accuracy decay of about 1 m in the three coordinates, are suitable to block adjustments for medium-small scale maps (1:10000 - 1:25000).

Beyond all these considerations - which should be examined for long time with the data we have not considered yet- it is important to underline that in our opinion, the most fundamental points for a good achievement of photo takings with GPS data are the following:

a) the flight project optimization;

b) the satellites geometry careful choice;

c) a right GPS antenna positioning on the aircraft - as to avoid that the wings or the rudder can shadow the satellite -;

d) active satellites number which must be great-equal to 5 in order to have a margin of safety.

6. REFERENCES

Ackermann, F., 1986. Use of Camera Orientation Data in Photogrammetry - a review. In: Proceedings of the ISPRS-Symposium (Comm. I), Stuttgart, pp. 93-100.

Ackermann, F., 1990. Kinematic GPS camera positioning for aerial triangulation. In: Proceeding of the Second International Symposium on Precise Positioning with the Global Positioning System, Ottawa, pp.1155-1168.

Ashkenazi, V., Hill, C., Summerfield, P., Westrop, J., 1990. High Speed, High Precision Suveying by GPS. In: Proceeding of the Second International Symposium on Precise Positioning with the Global Positioning System, Ottawa, pp. 524-536.

Astori, B., Forlani, G., Pinto, L., 1992. GPS-fotogrammetrico: un esperimento italiano sul poligono di Parma. In: Bollettino SIFET, No.1/1992, pp.133-155.

Crespi, M., Pinto, L.,.1991. Poligono di Lucera: compensazione della rete di raffittimento locale. In: Bollettino SIFET, No.1/1991, pp. 33-55.

Friess, P., 1988. Empirical accuracy of positions computed from airborne GPS data. In: Int. Arch. Photogramm. Remote Sensing., Kyoto-Japan, Comm. III, pp.215-224.

Friess, P., 1990. Kinematic GPS Positioning for aerial Photogrammetry - Empirical results -. In: Proceeding of the Second International Symposium on Precise Positioning with the Global Positioning System, Ottawa, pp.1169-1184.

Friess, P., 1991. Aerotriangulation with GPS - methods, experience, expectation. In: Proceedings of the 43rd Photogrammetric week, Stuttgart, Heft 15, pp. 51-60.

Pinto, L., 1992. Il rilievo cinematico GPS nella pratica topografica: un esempio applicativo. In :Bollettino SIFET. No.3/1992.