PHOTOGRAMMETRIC APPLICATIONS OF SERCEL GPS TR5S-B RECEIVER AT INSTITUT GEOGRAPHIQUE NATIONAL - FRANCE

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Abstract

IGN-F has realized in 1986 and 1987 two test campaigns with a GPS TR5S-B receiver built by SERCEL company. The aim of these operations was the evaluation of the contribution of this material, not only for navigation but mainly for photogrammetric purposes.
A first aspect of the paper concerns a description of the on-board system. Then results are presented when using two levels of accuracy for GPS data and testing differential measurements with a fixed receiver. Aerial triangulation computations take into account GPS data and several hypothesis are considered, concerning use of control groundpoints.
It is shown that it is possible to eliminate all control ground points for medium scales surveys, except one point at the center of the block for tying up to the geodetic network.
A last aspect concerns use of GPS data for aerial survey itself, even when NAVSTAR constellation configuration is degraded, and for automatic drawing up of flight indexes.

I) Introduction

The Global Positioning System NAVSTAR has been already presented in many other papers, concerning its civil applications in geodesy and for maritime, terrestrial and aerial navigation. But exploration of its abilities for photogrammetry has only begun recently.
In 1986 IGN has realized its first flights tests with SERCEL company. A preliminary step consisted of verifying the reception quality of GPS signals on an airplane and evaluating reliability of GPS position determination relative to photogrammetric calculation. These trials were done, at great scale, with a low speed Aerocommander aircraft. Another operation at medium scale has been conducted in 1987 with a fast Mystere 20 aircraft, for a more complete investigation of photogrammetric applications of GPS.
This paper presents the both flight tests and results after photogrammetric computation.

II) Description of the on-board equipment

. GPS receiver

For each operation IGN used a GPS TR5S-B receiver, built by SERCEL company ; this material has been already described in a previous communication, during ISPRS - Commission I symposium held in Stuttgart in 1986. Let us call again that this equipment comprises an antenna with its preamplifier, a receiving - processing unit, a colour CRT screen unit and a control keyboard (Fig 1). The receiver can simultaneously process all the signals coming from 5 satellites, on L1 frequency (1,57542 GHz) and C/A code. It is organized to realize an accurate measurement of pseudo-distance and phase, in each of the 5 channels, at a rate of 0,6 second.
The TR5S-B receiver is equipped of an internal precessor and a fast coprocessor for computing in real time, every 0,6 second, a complete 3D + T position solution using pseudoranges smoothed by accumulated phase.
The quality of antenna and its setting are dealt with care, in order to obtain a delay and a phase center position stable and independent of the direction of the arrival and to restrain multipath effects residuals.
From the static version of the receiver, developed for geodetic purposes, SERCEL company has extended applications to dynamic positionnement, first on sea, then on airplane. Development concerned antenna design and data processing by integrated phase techniques, in order to take into account speeds up to 250 knots and 1 g acceleration.
The first flightshave been realized on low-speed twin engine Aerocommander aircraft, using antenna and receiver developed for ships. The first results showed the interest to extend the dynamic capabilities of TR5S-B. For flight tests on twin jet Mystere 20, an omnidirectional DORNE-MARGOLIN antenna, with a half of sphere shape, was used at speeds up to 350 knots.

. Camera

Aerial survey, for each mission, was performed with a WILD RC10 camera equipped with a UAg lens cone of focal length 152 mm. Exposure pulse is picked up by a relay on a reed-switch which commands exposure mechanism of the lens cone, with a delay which is a function of exposure time. This delay can be determined experimentaly in laboratory : it is a constant for a given lens cone and a given exposure time. Its scale of size is some milliseconds for the usual exposure times. The exposure pulse is sent directly on an external port of the TR5S-B receiver.

. Synchronization and data recording

The receiver can deliver simultaneously raw data and calculated positions via two RS 232 C ports. The raw data message presents a fixed configuration : it is composed of ephemerides of each satellite (up to 5), GPS time, pseudoranges, phases, signal-to-noise ratio, etc, at a rate of 0,6 second. Recording is done on a Data Track 3 M cassette recorder.
The calculated data message is configurated in external mode,

according to a rate defined by external pulse, i e exposure pulse. This message contains, for each photograph a position solution given in geographic coordinates and determined by interpolation between two GPS positions separated by 0,6 second, for the exposure time. Geographic coordinates are referred to WGS 72 ellipsoïd for Amiens test site, to WGS 84 ellipsoïd for Lunel and Vichy test sites.

III) Test flights

Two series of experimental campaigns were realized in 1986, then in 1987 :

1. 1986 Flights

Two flights were performed over Amiens test site on :
- June 18, from 12 h to 13 h 30
- June 19, from 12 h 15 to 13 h 40

Flights characteristics

Airplane : Twin engine upper wing Aerocommander
Mean speed : 160 knots
Mean scale of the surveys : 1/4000
Flight configuration : 3 East-West strips of 25 to 28 photographs each.
- Received GPS satellites : SV 3-6-8-9-12

2. 1987 Flights

Two missions were realized over two 1/50 000 sheets :
- Lunel (near Montpellier, south of France) on August 19, from 9 h 15 to 10 h 15 local time
- Vichy, on August 20, from 9 h 15 to 10 h 15 local time.

These hours, not favorable for aerial surveys were imposed by reception conditions of the five GPS satellites : SV 6-8-11-12 -13.
During these flights, three simultaneous GPS records were done on known coordinates ground points :
- at Nantes, by SERCEL company
- at Creil, with a second TR5S-B receiver mounted by SERCEL
- on the center of each sheet of Lunel and Vichy (but unfortunately these informations will be unusable)

Flights characteristics

Airplane : Twin jet Mystere 20
Mean speed : 350 knots
Flight configuration :
- 4 East-West strips of 12 photographs
- 2 North-South strips of 8 photographs flown over East and West limits of the sheet in order to increase stiffness of the block composed of the four main East-West strips.

IV) Data analysis

The followed aim is to compare positions of the point of view given by GPS with the photogrammetric reference, calculated by aerial triangulation.

A preliminary step is a classical aerial triangulation computation controlled on known ground points. The results are checked on other known ground points (check points) in order to appreciate the quality of the photogrammetric reference which is different on the three sites.
A first strip consists of comparing GPS coordinates transformed in Lambert projection (Clarke 1880 ellipsoïd) with results of the previous aerial triangulation calculation. This comparison gives for each strip :
- on one hand, a translation bias, function of different parameters in relation with GPS system or on-board equipment (exposure delay - distance between antenna and camera)
- on the other hand a standard deviation which characterizes the accuracy relative to photogrammetric reference.
The following steps comprise introduction of GPS data in aerial triangulation when considering several hypothesis for this calculation :
- use of all control points
- use of only four control points at the angles of the block
- elimination of North-South strips, in order to appreciate their importance
- elimination of all control points and introduction of an imaginary point at the center of the block, what allows to simulate GPS on-site measurements.

V) Results

A) Amiens test site

On this site there was an old enough aerial triangulation network, established for a mission at a scale of 1/6000. The ageing of natural control points and transfer of these points on the 1986 photographs imply a medium accuracy of the photogrammetric reference as shown by residuals of aerotriangulation on control points :

Flight of June 18 (Amiens - I)

$\varepsilon x = 0{,}21$ m)
$\varepsilon y = 0{,}24$ m) $\varepsilon m = 0{,}27$ m
$\varepsilon z = 0{,}33$ m)

Flight of June 19 (Amiens - II)

$\varepsilon x = 0{,}29$ m)
$\varepsilon y = 0{,}38$ m) $\varepsilon m = 0{,}34$ m
$\varepsilon z = 0{,}36$ m)

For the following results, we consider only Amiens I flight :

a) Comparison between coordinates of the points of view and GPS measurements

Strip 1

$Tx = 0{,}51$ m	$\sigma x = 0{,}34$ m
$Ty = 1{,}22$ m	$\sigma y = 0{,}26$ m
$Tz = 3{,}55$ m	$\sigma z = 0{,}78$ m

STRIP 2

$Tx = -0,51$ m $\quad \sigma x = 0,30$ m
$Ty = 1,44$ m $\quad \sigma y = 0,48$ m
$Tz = 3,61$ m $\quad \sigma z = 0,23$ m

Strip 3

$Tx = 0,48$ m $\quad \sigma x = 0,20$ m
$Ty = 0,95$ m $\quad \sigma y = 0,21$ m
$Tz = 2,64$ m $\quad \sigma z = 0,28$ m

It is noticed that standard deviations are about of the same order than aerotriangulation residuals. But perhaps better accuracies would be possible with better control points.

b) Introduction of GPS measurements in aerotriangulation.

If GPS measurements are introduced in aerotriangulation computation with all the control points, there is no significant effect.

c) It is interesting to reduce the number of control points. If we keep only 4 points known in x y z at the angles of the block the results are as follows, on the check points, for the whole block :

$\sigma x = 0,22$ m
$\sigma y = 0,53$ m
$\sigma z = 0,70$ m

This result can appreciably vary according to the choice of the four kept control points.

d) If we continue this trial, we can keep only one point at the center of the block. The results on the same check points as previously are as follows :

$\sigma x = 0,51$ m
$\sigma y = 0,52$ m
$\sigma z = 1,55$ m

It is noticed that results remain acceptable for planimetry but are degraded in altimetry. The main cause is a lack of transversal stiffness of the block. For this reason two North-South strips have been added to flight configuration of 1987, in order to obtain a better transmission of altimetric constants.

B) Lunel test site

For this sheet computations have been conducted using the three kinds of available GPS data :

- pseudoranges smoothed by phase, with trajectographic correction by differential processing, using Creil or Nantes GPS records.
- pseudoranges smoothed by phase, without differential processing
- only pseudoranges

Aerial triangulation of this mission has been calculated using a 1985 ground preparation at a scale of 1/30000, with transfer on 1987 aerial survey. Adjustment results on control points are as follows :

- for planimetry : 0,75 m
- for altimetry : 0,60 m

what appears normal for transferred points at a scale of 1/30000

1) Comparison between GPS positions and coordinates of the points of view.

A first aspect concerns medium position of the whole block relative to the ground reference. Computation is done from differential data corrected from main GPS systematic errors : error of the satellites, ephemerid errors and, partly, ionospheric delays because the fixed receiver was far enough from the test flight. Distance between antenna and point of view, and geoïd height relative to Clarke ellipsoïde are also corrected. In these conditions the translation for the whole block has the following components :

$T_x = -3,02$ m
$T_y = -1,37$ m
$T_z = -0,51$ m

Individual differences of the strips relative to medium reference of the block are as follows :

Strips	A	B	C	D	E	F	G
x (in m)	- 0,83	+ 0,90	- 1,14	+ 0,82	+ 0,26	+ 0,39	- 0,09
y (in m)	- 0,34	+ 0,05	- 0,08	+ 0,79	+ 0,71	- 1,09	+ 0,09
z (in m)	- 0,33	- 0,72	- 0,33	- 0,94	+ 0,66	+ 0,85	+ 0,17

It is noticed that reception losses when the aircraft is changing of strip are not completely corrected by the manufacturer software ; strips are only linked by the photogrammetric block. If bias for each strip is eliminated it is obtained standard deviations between GPS positions and points of the view for the whole block, with the three kinds of GPS data :

	Differential	Pseudoranges and phases	Pseudoranges
σ_x	0,39 m	0,75 m	4,09 m
σ_y	0,41 m	0,79 m	2,60 m
σ_z	0,26 m	1,14 m	4,20 m

2) As for Amiens test site, GPS measures contribution in adjustment with all control points is negligible.

3) If it is kept only four control points at the angles of the block it is obtained the following results, with the three kinds of GPS data :

	Differential	Pseudoranges and phases	Pseudoranges
σx	0,78 m	0,77 m	1,29 m
σy	0,63 m	0,64 m	2,32 m
σz	0,51 m	0,53 m	0,98 m

4) When all the control points are eliminated it is kept only one imaginary point without error, at the center of the block, with the following results :

	Differential	Pseudoranges and phases	Pseudoranges
σx	0,72 m	0,75 m	1,04 m
σy	0,67 m	0,70 m	1,27 m
σz	0,56 m	0,63 m	0,93 m

Comparison of the previous results involves the following remarks :

1) results are not really affected by elimination of control points of which accuracy seems lower than those of GPS measurements. This fact can be explained by the kind of the used control points (it is natural points) and the accuracy losses due to transfer of points on the 1987 photoflight.

2) Contribution of differential measurements appears negligible

3) Results with only pseudoranges are not so bad as it was feared, particularly with an imaginary control point. In fact it is the photogrammetric block itself which ensures smoothing function.

4) North-South strips play an important part to ensure stiffness of the block, for instance in altimetry. When these strips are eliminated from photogrammetric adjustment there is no important effect in planimetry but a high degradation in altimetry.

C) Vichy test site

For this sheet we have only differential and pseudoranges smoothed by phase GPS data.
This sheet has a better ground equipment that the Lunel one because there was a ground preparation just after the aerial survey, in 1987. Aerial triangulation gives, therefore, better results, with adjustment residuals on control points as follows:

- in planimetry : 0,55 m
- in altimetry : 0,49 m

1) Comparison between GPS position and coordinates of the points of view.

As for Lunel we have first determined the bias for the whole block.

Tx = - 3,23 m
Ty = - 0,99 m
Tz = + 0,58 m

its components are about the same that the Lunel one. It's not a surprise because Vichy flight was done just one day after Lunel, at the same time and in the same atmospherical conditions.
Individual differences for each strip, relative to medium reference of the block are as follows :

Strips	A	B	C	D	E	F
x (in m)	+ 0,30	- 0,47	+ 0,71		- 0,20	- 0,38
y (in m)	- 0,27	- 0,07	+ 1,03		- 0,22	- 0,48
z (in m)	- 0,23	- 0,93	- 0,38		+ 0,59	+ 0,97

<u>Note</u> : GPS data for D are not available

- Standard deviations for the whole block, after elimination of bias for each strip, with the two available kinds of GPS data.

	Differential	Pseudoranges and phases
σx	0,51 m	0,89 m
σy	0,46 m	1,16 m
σz	0,35 m	1,34 m

Results are inferior to those of Lunel although aerial triangulation is of a better quality.

2) Introduction of GPS data in adjustment with all the control points

As for the previous test sites, GPS contribution appears negligible.

3) Idem, when keeping only four control points at the angles of the block.

	Differential	Pseudoranges and phases
σ_x	0,55 m	0,58 m
σ_y	0,51 m	0,53 m
σ_z	0,66 m	0,76 m

4) Idem, when keeping only an imaginary control point without error at the center of the block.

	Differential	Pseudoranges and phases
σ_x	0,65 m	0,62 m
σ_y	0,64 m	0,76 m
σ_z	0,88 m	1,00 m

All the notices previously done about Lunel test site are confirmed ; but results with one point appear less good.

VI) Use of GPS data aerial navigation

The on-board system allows to determine in real time position of the points of view with an accuracy of about one meter, if five satellites are used. These data are easily usable for navigation, in order to calculate and display all the parameters needed by the navigator : distance relative to the flight plan, remaining distance on a strip, etc.
Another interesting application is automatic drawing of flight indexes. That needs to measure and record roll and pitch of the aircraft at the exposure time, in order to determine the coordinates of the center of the photograph. This operation is done with a twin gyros unit, mounted on the camera. Roll and pitch are digitized and recorded on HP 9825 calculator. Such a test was done in 1986 on Amiens test site with transfer of the centers of the photographs on a 1/25000 map, with an automatic HP plotter system. The obtained accuracy is at least as good as manual identification.

The August 20 test flight has brought interesting ideas about capabilities of the present GPS configuration. For a photogrammetric use we must have five well-placed satellites, always the same for the duration of the flight. The Vichy sheet was flown with these conditions ; then, other sheets were photographied with poorer conditions. GPS receiver operated in automatic mode : it selected itself the satellites and validated measures until an elevation of 0° (instead of 5° in normal conditions). Three satellites could be received until 13h50, what allowed satisfactory positions for navigation, better than those obtained by any other autonomous navigation means ! With three satellites a position is calculated using a fourth data : internal clock of the receiver, aircraft altitude measured by onboard altimeter or a pressure sensor. Accuracy could be enhan-

ced by a cesium clock, more precise than the internal clock of the receiver.
With the present GPS constellation of six satellites it is possible on a given place to have two periods of six hours each day for navigation of surveys and remote sensing missions.

VII) Conclusion

IGN experimentations conducted with SERCEL company since 1986 demonstrate all the interest of the GPS contribution for photogrammetry.
At medium scale (about 1/30000) Vichy and Lunel test flights show that all ground preparation can be eliminated except one control point at the center of the block for the connection to the geodetic network.
Contribution of differential measurement is not obvious, on Vichy and Lunel. These measures allow to reduce systematisms for each flight strip but have little influence on final accuracy. Use of on-board pseudorange smoothed by phase receiver at high rate (0,6 second) seems therefore to be the best solution for photogrammetry. A second receiver on the ground would imply operational difficulties and cost increasing but would not really bring improvement of accuracy.
Use of a simpler receiver based on only pseudoranges could be perhaps considered ; but a high rate remains absolutely necessary. It is not the case for these materials.
At great scale the Amiens study cannot allow to conclude, due to the poor quality of control points and the lack of transversal flight strips for stiffness of the block. Another study is foreseen, in order to determine the greatest scale for which GPS data would be able to replace ground preparation.
GPS measures are destined to generate in the near future very deep changes in photogrammetric methods, by elimination of the heavy and expensive ground preparation, at least for medium scales.

Fig 1 _ On-board GPS equipment for photogrammetric applications

Principle diagram