The Photogrammetric Journal of Finland, Vol. 13, No. 1, 1992

KINEMATIC GPS IN AEROTRIANGULATION IN FINLAND

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Abstract

Two test flights were carried out to find out how well kinematic GPS can be applied in aerotriangulation in Finland. Only the results and the experience from the first flight is dealt with in this article, because no results are yet available from the second flight. The first flight was carried out under unfavourable conditions and the block is small. The results still show the great potential for the use of GPS coordinates in a combined bundle block adjustment. The number of ground control points can be considerably reduced, which again leads to big savings in the targeting work. The results of the second more practically oriented flight will be of great importance when drawing the final conclusions.

1 INTRODUCTION

The NAVSTAR Global Positioning System (GPS) has for some years now been tested for geodetic and photogrammetric applications. At the moment the system is widely applied in practical geodetic works. Also airborne kinematic camera positioning by GPS has reached the point where practical application is the next step /1/. One limiting factor is the current state of the GPS system. At the moment there are 19 satellites available, which means that for some periods of the day the number of satellites above the horizon is less than the required minimum of four. This limitation is expected to disappear by March 1994 /6/ when all 24 Block II satellites are expected to be operational.

One of the main tasks in photogrammetry is the determination of the aerial camera position by GPS at the moment of exposure. The GPS coordinates of the aircraft antenna at exposure time can be introduced as additional observations into a combined block adjustment. The main advantage of this additional data is the considerable reduction in the need of ground control points. This is definitely of interest in areas with poor geodetic networks (for example undeveloped countries). Areas with well established geodetic control should also be considered, especially if the area is of some size. The targeting work is time consuming and expensive.

Quite a number of test flights and simulations have been carried out in the field of GPS-supported aerotriangulation /1/,/2/,/4/,/5/,/7/, but none in Finland until 1991. The first flight of a more experimental character was carried out in August 1991 (the Nummela-Lohja block). A second flight was carried out in May 1992 (the Eura block). This was a flight for the Finnish base map production. The purpose of the second flight was to look at possible problems with a long distance between the stationary receiver and the area to be photographed, and how a long flight mission will affect the result. The work was a joint project between the Finnish Geodetic Institute (FGI) and the National Board of Survey (NBS). This article deals with the experience and the results only from the first flight, because no results are yet available from the second flight. A more complete report will be presented later.

2 MEASURING PROCEDURE AND DATA PROCESSING

2.1 Equipment and measuring principle chosen

The aircraft used was a Turbo Commander 690A belonging to NBS. It was equipped with a Wild RC20 aerial camera. The camera was connected to an Ashtech MD-XII GPS receiver. The antenna, a Sensor Systems specially designed for aircrafts, was mounted on top of the aircraft fuselage almost vertically above the aerial camera (see Section 2.2). It was a single frequency antenna. The recording rate was chosen to be 0.5 seconds. A stationary receiver of the same type was on the ground (at the airfield) working as a reference. The principle of relative positioning using differences of carrier phase observations was used. Due to the single frequency aircraft antenna only carrier wave phase measurements on L1 could be utilized, although the receivers were of the dual frequency type. The exposure time signals of the aerial camera were recorded and stored in a file in the GPS receiver memory.

The measurements of the aerial photos were carried out on a Kern DSR1 analytical plotter at FGI.

2.2 The eccentricity between the GPS antenna and the aerial camera

The eccentricity between the GPS antenna and the aerial camera was measured using a tachymeter. The horizontal components of the eccentricity are rather small (e_x = 0.055 m, e_y = 0.260 m), thus the effects of camera rotation (crab setting) onto the eccentricity could be neglected. The crab setting of the camera was not changed during a flight strip and it was not recorded. Figure 1 shows the position of the GPS antenna with respect to the aerial camera.

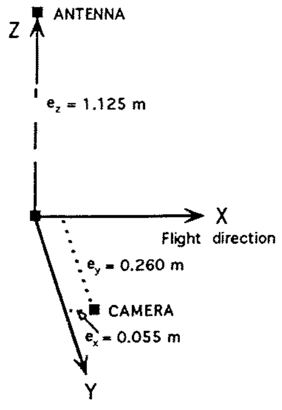


Figure 1. Antenna eccentricity

2.3 Preprocessing of the GPS data

The data from the test flight was preprocessed using the GPPS program package from Ashtech. Due to unrecoverable cycle slips the data could not be computed as a whole. The data had to be processed forward in time as well as backward in time. The other part of the data, though, covered the whole photography.

2.4 Treatment of the GPS antenna coordinates

The GPS coordinates were transformed from WGS 84 to the Finnish KKJ system (Gauss-Krüger). The positions of the GPS aircraft antenna at exposure time were computed using a polynomial interpolation.

The output signal from the aerial camera to the GPS processor does not represent the mid-exposure time. The GPS receiver registers the rising edge of the pulse, which is delayed by 10 ms ± 0.15 ms (milliseconds), compared to the mid-exposure time (see Fig. 2). The registration of the signal can be changed to represent the mid-exposure time. There are also certain other inaccuracies in the registration of the exposure time amounting to about ± 0.05 ms. That is, the registered time signal is delayed by 10 ms ± 0.16 ms with respect to the mid-exposure time. The GPS coordinates were corrected for this time delay using the attitude data from a conventional block adjustment and the speed of the aircraft. These corrected GPS coordinates were introduced into the combined block adjustment. The inaccuracy of the exposure times is ±1.6 cm if the speed of the aircraft is 100 m/s (360 km/h) which is well inside the required limit.

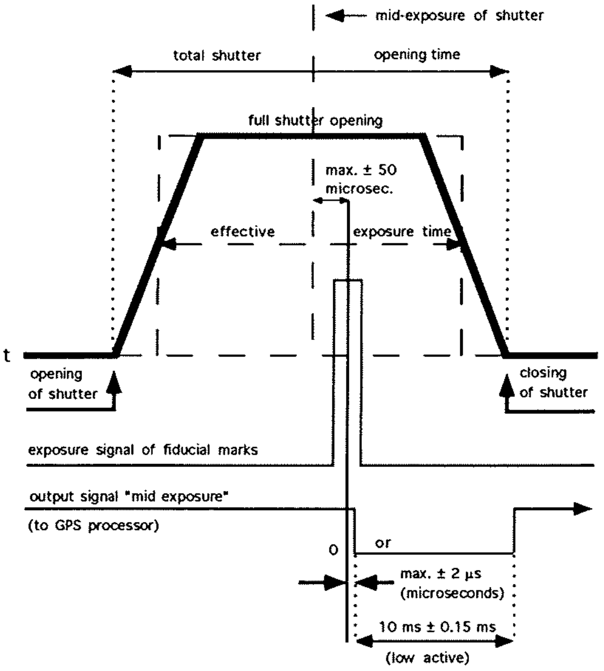


Figure 2. Mid-exposure signal for kinematic GPS positioning using Wild RC20 aerial camera.

2.5 Extensions of the bundle block adjustment program ESPA

The bundle block adjustment program ESPA (Expert System for Photogrammetric Analysis) /8/ was extended to treat GPS antenna position coordinates as additional observations in a combined block adjustment. Other reports on kinematic GPS positioning have confirmed that the GPS aircraft positions normally are affected by time dependent drift errors /1/,/2/,/3/,/5/,/7/. These errors can be corrected for by including drift parameters as unknown parameters into the combined block adjustment. The drift parameters also include an offset for each coordinate. The drift has shown to be almost linear. Introduction of second order terms has been proven to give unfavourable results /3/. The linear drift parameters can be treated as common for the whole block provided that the GPS trajectory is continuous. In many cases separate sets of linear drift parameters are needed for each strip or for different parts of the block. Different solutions for the drift parameters were introduced into ESPA.

3 ANALYSIS OF THE NUMMELA-LOHJA BLOCK

3.1 Description of the block

The test flight was carried out on the 29th of August 1991 in the Nummela-Lohja area about 50 km west of Helsinki (see Fig. 3). The block covers part of a bigger area that was targeted and photographed in spring time for the Finnish base map production (1:5000). Because of the satellite configuration the flight had to be carried out in the afternoon, and the shadows to some extent disturbed the measurements of the photos. Some clouds appeared during the flight and caused some problems with the measurements. Quite a few control points could not be found, especially vertical control points. The receivers kept track on 4-5 satellites during the flight. The satellite configuration provided a fairly good geometry with PDOP values below 6. The ground control consisted of 17 XYZ points, 2 XY points and 34 Z points.

The technical data of the flight:

Date of flight : August 29th, 1991
Size of area : 10 x 20 km
Aircraft : Turbo Commander 690A
Camera : Wild RC20
Focal length : 214.10 mm
Average speed : 360 km/h
Duration of flight mission : 60 min
Flight altitude : 3400 m
Photo scale : 1:16000
Overlap : p = 60%, q = 30%
Number of photos : 43 (in four strips)
GPS receivers : 2 Ashtech MD-XII
GPS aircraft antenna : Sensor Systems
Recording rate : 0.5 sec
Antenna-camera offset : e_x = 0.055m, e_y =0.260m, e_z = -1.125m

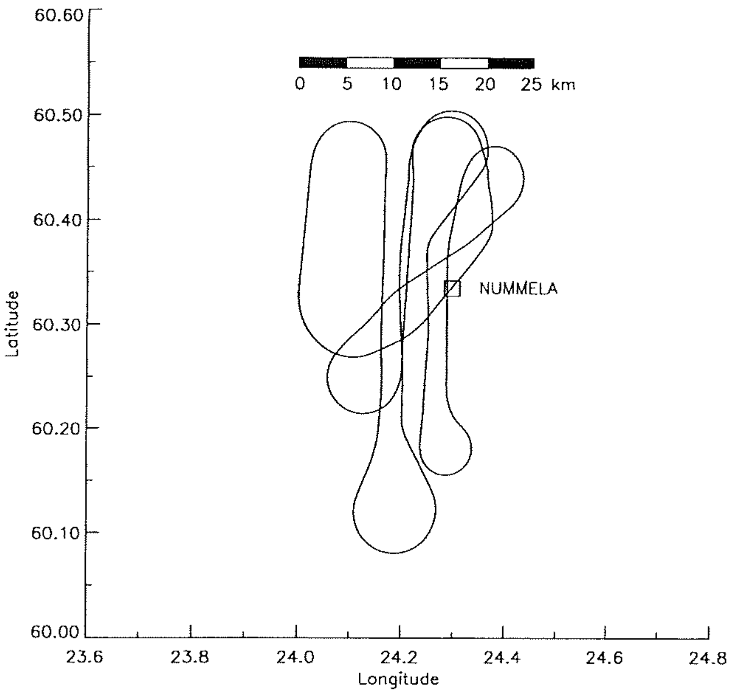


Figure 3. Flight path Nummela-Lohja

3.2 Analysis of the results

The unfavourable circumstances under which the test flight was carried out to some extent affected the final results. Fig. 4 shows the control point configuration of the block. Half of the Z control points are of rather poor quality (17 out of 34), which weakens parts of the block. They were weighted down in the adjustment. They are naturally used only in the case with full ground coordinate control. As mentioned above some of the control points could not be found due to missing targets. The tie points are natural points.

The accuracy of the ground control points is set to σ_{GC} = ±10 cm except for the poorer half of the Z control points (±50 cm). The image coordinate accuracy is set to σ_0 = ±5 µm. Different values for the accuracy of the GPS camera position coordinates were tested, but no distinction between the horisontal coordinate components and the vertical coordinate component were made. The accuracy in the analysis presented below is chosen to be σ_{GPS} = ± 10 cm. Both independent drift parameters for each strip and common drift parameters for the whole block were tested. In the analysis below the check points are identical with the control points not used in the block adjustment. The poorer Z points are not used as check points.

Let us first look at the two drift parameter solutions for different ground control configurations (see Table 1). The results show the r.m.s. accuracy of the check points. The case

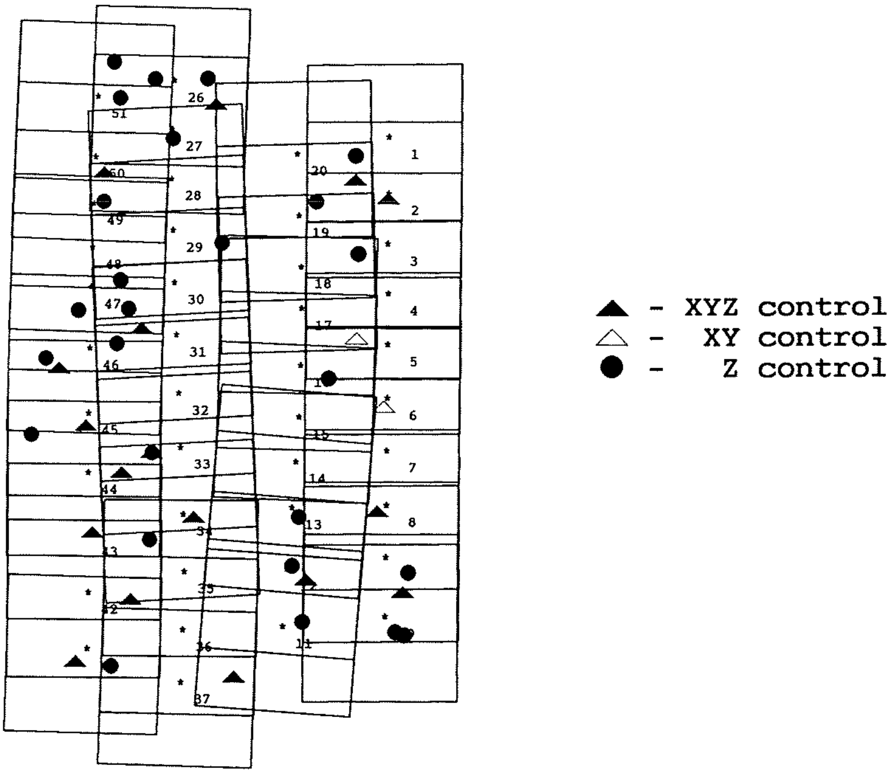
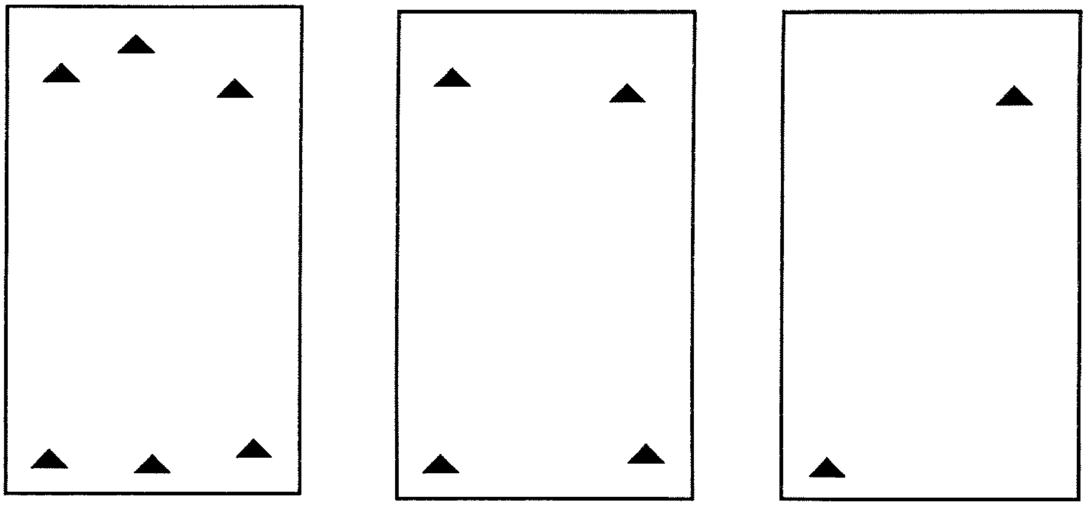


Figure 4. The ground control configuration of the Nummela-Lohja block.


a) 6 XYZ points

b) 4 XYZ points

c) 2 XYZ points

Figure 5. Different ground control configurations.

with 6 XYZ control points (see Fig. 5a) shows that both solutions are equally good. The same can be said if more ground control is used (not shown here). With 4 XYZ control points located at the corners of the block (see Fig. 5b) better results are achieved using common drift parameters for the whole block, but only in Z. The same can be said in the case of 2 XYZ control points (see Fig. 5c) located in opposite corners of the block, where common drift parameters for the whole block are clearly better, especially in Z. This is all according to theory. Though 2 XYZ control points is a more theoretical case, it shows the great potential of GPS-supported aerotriangulation.

Table 2 shows the drift parameters using full ground control in the combined bundle block adjustment. The case with stripwise drift parameters shows a big inconsistency in both drifts and offsets between the strips. The maximum drift is as high as 37 cm per minute. The drifts are much smaller when common drift parameters for the whole block are chosen with all three drifts in the range of 0.7 - 4.2 cm per minute. On the base of this, it can be concluded that a model with common drift parameters for the whole block is better suited for the Nummela-Lohja block.

Ground cont.	Block adjustment		No. of ch.pts.		R.m.s. accuracy of check pts.		
	Meth.	Drift	XY	Z	X	Y	Z
6 XYZ	STD	-	13	28	±0.105 m	±0.131 m	±0.500 m
	GPS	strip	13	28	±0.100 m	±0.129 m	±0.226 m
	GPS	block	13	28	±0.111 m	±0.126 m	±0.247 m
4 XYZ	STD	-	15	30	±0.214 m	±0.193 m	±0.523 m
	GPS	strip	15	30	±0.145 m	±0.165 m	±0.551 m
	GPS	block	15	30	±0.159 m	±0.147 m	±0.336 m
2 XYZ	GPS	strip	17	32	±0.394 m	±0.189 m	±3.436 m
	GPS	block	17	32	±0.284 m	±0.124 m	±0.382 m

STD - conventional bundle block adjustment
GPS - combined bundle block adjustment with GPS
strip - stripwise drift parameters
block - blockwise drift parameters

Table 1. Results of bundle block adjustment.

Drift par. set	Drift parameters		
	X	Y	Z
Block	-0.071m - 0.00011m/s	-1.239m - 0.00061m/s	2.345m + 0.00070m/s
Strip 1	-0.343m + 0.00553m/s	-1.424m + 0.00465m/s	2.408m + 0.00038m/s
Strip 2	-0.081m + 0.00267m/s	-1.460m + 0.00569m/s	2.820m - 0.00181m/s
Strip 3	-0.479m + 0.00085m/s	-2.046m - 0.00374m/s	3.032m + 0.00018m/s
Strip 4	-0.519m + 0.00622m/s	-1.498m -0.00093m/s	3.339m + 0.00191m/s

Table 2. Drift parameters using full ground control in the bundle block adjustment.

Both conventional and combined bundle block adjustments are presented in Table 1 for different ground control configurations. The biggest advantage of the combined adjustment is the clear improvement in Z, but with 4 XYZ control points the X and Y are also slightly better. The X and Y are quite well fixed using conventional block adjustment with 4 or 6 XYZ control points because the size of the block is small. The combined adjustment with only 2 XYZ control points shows remarkably good results. Except from the X coordinate, combined block adjustment with 2 XYZ control points gives better results than conventional block adjustment with 6 XYZ control points provided that common drift parameters for the whole block are chosen.

4 THE TARGETING OF GROUND CONTROL POINTS - CURRENT STATE AND FUTURE VISIONS

The targeting of ground control points is a considerable part of a mapping project. If this work could be reduced to a minimum by utilizing GPS in the aerotriangulation both time and money will be saved.

Let us take an example: The Eura block (the second test) is a block of average size for the Finnish base map production. It consists of 264 photos in 10 strips. 253 ground control points (87 XYZ and 166 Z) were targeted for this flight mission. The targeting was based on the existing geodetic network, but also some new points were measured using GPS (about 10% of all the control points). The XYZ control points are often not easily accessible. Provided the results of the Eura test flight are positive with respect to the usage of GPS in aerotriangulation in Finland, the number of ground control points could certainly be reduced to 1/10 of what is normal. In other words it means that more than 200 control points can be dropped out. However some investments have to be considered. The GPS receivers are still quite expensive, but the prices are expected to fall significantly. Even with today's prices the extra expense per flight mission caused by the cost of the receivers is small compared to the savings in the field work.

5 CONCLUSIONS

The test flight Nummela-Lohja was carried out under quite unfavourable conditions. The results still show the great potential of GPS-supported aerotriangulation. Common drift parameters for the whole block were found to give the best results. Even a more theoretical case with only 2 XYZ ground control points gave remarkably good results for the combined bundle block adjustment. A solution with 4 XYZ ground control points located at the corners of the block plus two chains of vertical control points across the strips at either end would give satisfying results. This is based on a side overlap of 30%. Two cross strips across the block at either end, replacing the two chains of vertical control, has been shown to give better results /1/, but it is also a matter of cost and benefit.

The second flight (Eura) was of a much more practical character. It was a photo flight mission for the Finnish base map production. The distance between the stationary receiver at the airport and the area to be photographed was in the range of 160-200 km. The whole flight mission lasted 4 hours. This is the normal case rather than the exception in Finland. Even longer distances are not rare. It is most important that the reference receiver is kept at the airport, because the decision on which area to photograph has sometimes to be taken after take-off due to changing weather conditions. If the weather is good even more than one area can be photographed (or at least partly) during a mission. The results of the Eura block will hopefully tell how well suited GPS-supported aerotriangulation is for mapping purposes in Finland. If the accuracy requirements can be met, the targeting work can be considerably reduced, saving both time and money.

One final remark about the reliability of the GPS measuring system. There are certainly cases where it can fail due to technical problems. However it is unlikely that a whole flight mission will be spoilt because the problems are often of more temporary nature. The equipment is developing all the time and with the introduction of fast ambiguity fixing (on-the-fly) techniques the reliability of the system increases further.

6 ACKNOWLEDGEMENTS

The help from Mr. Matti Ollikainen of FGI is gratefully acknowledged. He was much involved in the practical work of the first test flight and he later processed the GPS data. The practical and theoretical assistance of Mr. Juha Jaakkola (FGI) is also much appreciated.

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