OPERATIONAL BLOCK ADJUSTMENT WITHOUT CONTROL POINTS

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Abstract

The highest accuracy of kinematic GPS-positioning for photogrammetric applications has been achieved with carrier phase observations. The handling of the carrier phase includes the problem of the ambiguity solution, and so systematic errors could not be avoided. Now with an improved kinematic C/A-code positioning supported by INS it is possible to reach an absolute accuracy of of the projection centers of ±0.2m up to ±0.3m without the problems of the ambiguity solution. This has been achieved close to on-line, based on a broadcasting reference station. With such GPS-positions the ground coordinates determined by bundle block adjustment without control points can reached an accuracy of approximately ±0.2m for X, Y and Z.

INTRODUCTION

Due to the strong economic effect the percentage of blockadjustments using projection center coordinates determined by kinematic GPS-positioning is growing from year to year. The progress could be faster if the GPS-positioning would be more reliable. Some companies stopped the use of combined block adjustments for precise point determination (< ±30cm) because of failures of the kinematic GPS-positioning which could not be seen during the photo flight. In the case of the determination of subsidences also a later survey of additional control points was not possible. This problem can be solved in using active GPS-reference stations and a close to on-line computation of the positions.

The GPS solution can be based on the C/A-code or the carrier phase. The coordinates based on the C/A-code usually have been limited to an accuracy of approximately ±1.5m. On this accuracy level no real problems are existing. The accuracy can be improved by a Kalman filtering. The more precise carrier phase includes the problem of the ambiguity solution - only the phase will be measured but the number of wavelength from the receiver antenna to the satellite is unknown and has to be estimated by different methods. The correct ambiguity determination is usually not possible by kinematic GPS-positioning causing unknown systematic errors which are constant and mainly linear time and location depending up to a loss of reference. In a usual photo flight during turn around from one flight strip to the next, the connection to some satellites is lost, causing cycle slips, that means a change of the ambiguity solution. By this reason the solution of a bundle block adjustment with projection centers determined by GPS must include the computation of the unknown shift and drift parameters of the GPS-projection center coordinates individually for every flight strip. That means 6 additional unknowns for every flight strip have to be included. If only 4 control points are available, 2 crossing flight strips are required for a sufficient solution - see figure 1.
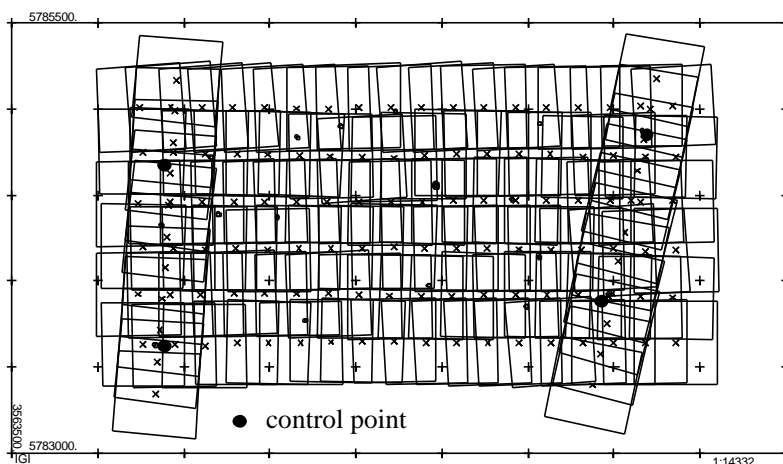

figure 1: typical photo arrangement for the determination of the GPS shift and drift values different for any flight strip with 4 control points

Under operational conditions up to now a block adjustment without control points is only possible based on the C/A-code. If the receiver is combined with an inertial navigation system (INS), also a loss of lock can be bridged without problems.

The company IGI, Hilchenbach, Germany, has developed the CCNS Aerocontrol which includes a 12-channel DGPS supported by an INS. With the inertial measurement unit it is possible, to respect the offset from the GPS-antenna to the projection center of the camera directly, to bridge a loss of lock and to use also permanent reference stations using a larger time interval for recording like 3 seconds. The standard configuration is operating with a broadcasting reference station, so all required components can be checked on-line and the projection centers can be computed during the photo flight. A 16-state Kalman filtering of the CA-code signals is improving the accuracy. The

DGPS is recorded once per second, the INS 50 times per second. The datum (relation between the WGS84-coordinate system used by GPS to the national net coordinate system) and the geoid (figure 2) is respected, so it is possible to determine directly the correct projection center coordinates which can be used in the bundle block adjustment.
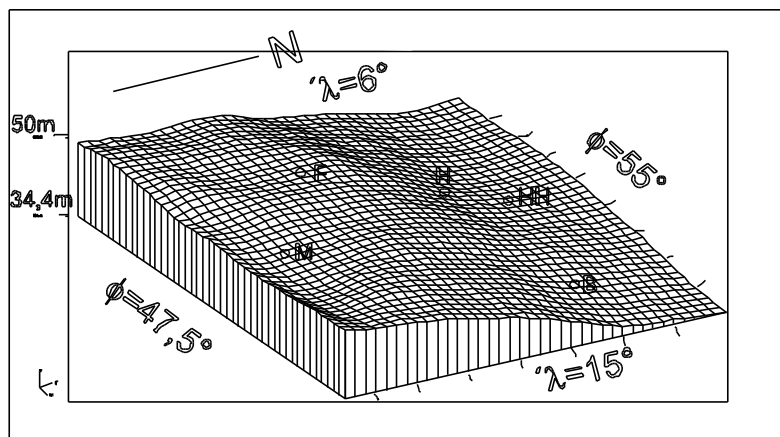
figure 2: geoid in the area of Germany

EMPIRICAL RESULTS

The block shown in figure 1 has been inspected in detail. It includes 130 photos, with 3 flight strips flown from East to West, 3 flight strips flown from West to East and 2 crossing strips. The photo scale is in the range of 1:2100. 18 well distributed control points are known with an accuracy of approximately ±1cm in X, Y and Z. The bundle block adjustment, the analysis and the graphical representations have been made with the Hannover program system for bundle adjustment BLUH.

The discrepancies in the projection centers between the coordinates determined by controlled bundle block adjustment and CCNS Aerocontrol (figure 3) are indicating a remaining error of the antenna offset in the range of 0.3m in the X-component.

figure 3: discrepancies at projection centers
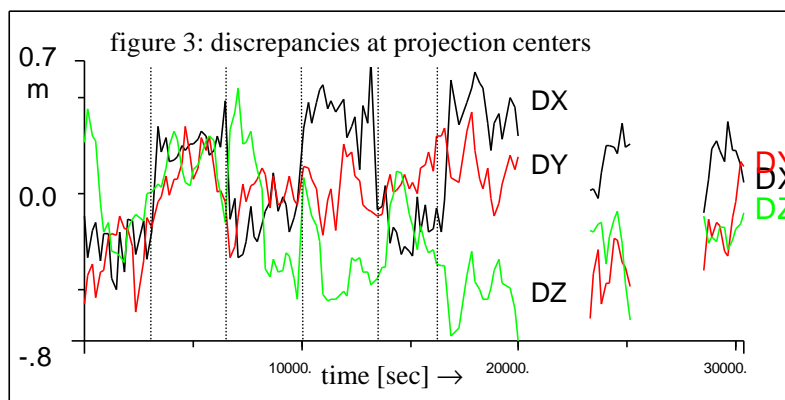
type of fitting	RMSX [cm]	RMSY [cm]	RMSZ [cm]
no	31.1	23.5	34.4
shift	29.4	22.9	28.6
drift (linear time depending)	27.7	23.1	26.0
time • time	26.6	20.0	24.0
time • time • time	26.6	18.6	23.2

table 1: *root mean square differences of projection center coordinates determined by reference adjustment with all control points against the positions determined by CCNS AEROCONTROL - differences improved by elimination of systematic errors for all projection centers of the block together*

type of fitting in any strip	RMSX [cm]	RMSY [cm]	RMSZ [cm]
no	31.1	23.5	34.4
shift	11.9	13.8	20.4
drift (linear time depending)	12.0	13.0	15.6
time • time	11.5	12.1	11.3
time • time • time	11.1	11.1	10.1

table 2: *root mean square differences of projection center coordinates determined by reference adjustment with all control points against the positions determined by CCNS AEROCONTROL - differences improved by elimination of systematic errors individually for every flight strip*

An analysis of the GPS-coordinates shows no major general systematic errors but shifts different for every flight strip. The absolute accuracy is reduced from ±23.5 to ±34.4cm down to ±11.9cm to ±20.4cm if systematic errors are excluded individually flight strip by flight strip (program GPSPL of program system BLUH). Only the Z-component can have a small improvement if also the drift is reduced. The accuracy of the projection centers determined by

controlled bundle block adjustment are negligible against these differences. The reference adjustment was possible with a sigma0 = ±13.5µm, the rms differences at the control points are in the range of ±1.6 up to ±2.8cm and the projection centers do have an inner accuracy of ±1cm up to ±4cm, only the projection centers of the last photos of the flight strips are limited to ±8cm.

The root mean square differences of the GPS-coordinates of the projection centers are not identical to the attainable accuracy of the ground points because individual errors are reduced by the process of block adjustment and the small errors of the offset can be determined and respected due to the oscillating flight direction. The results of the combined adjustment should be compared with a block adjustment with minimum control, that means, with 4 control points. With crossing flight strips such a block can be adjusted but especially the vertical accuracy is limited as it can be seen in figure 4 and table 3.
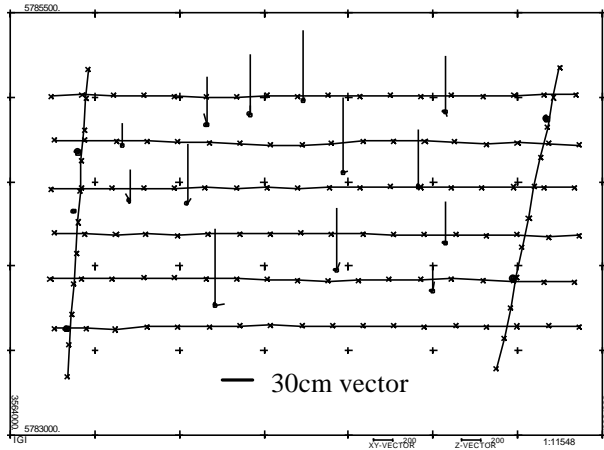

figure 4: adjustment with 4 control points, without GPS-coordinates
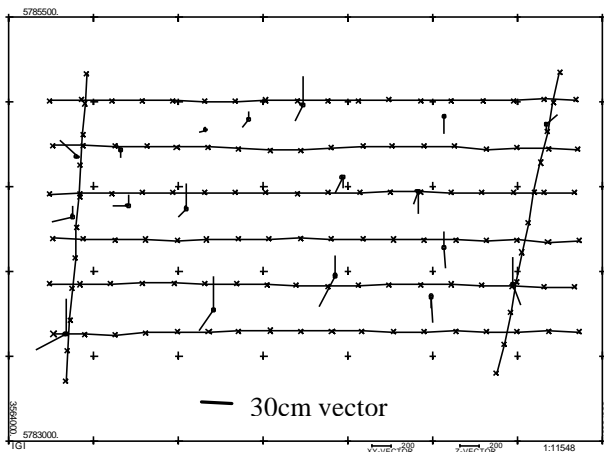- discrepancies at check points

figure 5: adjustment without
control points
- discrepancies
at check points

The determination of the GPS-coordinates has been done twice, at first close to on-line with a broadcasting local reference station and later also in relation to a permanent reference station of the surveying department with a distance of approximately 25km from the block area. The second computation has not a so good accuracy and also larger systematic errors occurred.

	control points	sigma0 [µm]	SX [cm]	SY [cm]	SZ [cm]
reference **no GPS**	*18*	*13.5*	*1.6*	*2.5*	*2.8*
minimal control **no GPS**	*4*	*13.6*	*3.4*	*5.2*	*48.2*
local reference 130 photos	4	13.5	2.9	3.7	14.0
"	1	16.8	6.6	9.0	17.1
²	**0**	**19.3**	**12.3**	**17.2**	**19.4**
local reference 110 photos	4	14.0	4.6	6.6	15.3
"	1	19.3	8.3	13.4	27.1
²	**0**	**19.8**	**13.1**	**20.9**	**20.4**
reference 25km 130 photos	4	15.6	4.9	7.4	10.4
"	1	17.5	6.0	8.4	11.8
²	**0**	**36.5**	**33.0**	**16.3**	**269.2**
reference 25km 110 photos	4	13.1	6.5	7.4	14.3

"	1	21.3	13.2	12.7	22.6
2	**0**	**38.5**	**38.0**	**15.6**	**271.4**

table 3: accuracy of independent check points determined by combined block adjustment, 130 photos = all photos, 110 photos = only flight strips East - West

The results of the combined bundle block adjustment listed in table 3 demonstrates the possibility of a block adjustment without control points. No refinements of the GPS-data have been made. The photo measurements have been made by the photogrammetric company Kirchner & Wolf Consult under usual conditions and the GPS-computations have been made by IGI, Hilchenbach. That means this is not a special block handled under test conditions of a University.

The block adjustment with all photos, no control points and the GPS-data in relation to the local reference station has an accuracy determined by independent check points better than ±20cm for all coordinate components. Also if the block is handled without crossing flight strips, the standard deviations are not exceeding ±21cm. Of course the results with 4 control points are better, especially in the horizontal components. The vertical results with 4 control points are not so much better. With one control point only the horizontal accuracy could be improved.

The block adjustment in relation to the reference station in a distance of 25km shows similar results for the adjustment with 4 or 1 control point(s). Without control points the vertical component is shifted 2.7m. Also the X-component is not so good with ±33cm and ±38cm. Only the Y-component is in the same range.

The block adjustment based on 4 control points has been made with additional unknowns for the compensation of the shift and drift values (linear time depending) of the GPS-coordinates individually for every flight strip. The influence of the drift was very small or nearly negligible. With only one control point a drift compensation is not possible and shift parameters depending upon the flight direction in x' and y' have been used together with shift parameters for X, Y and Z for all photos of the block together. That means, 5 parameters (shift in x', y', X, Y, Z) have been used in total for the compensation of systematic GPS-effects. So in addition to a datum shift also errors of the antenna offset can be eliminated if 1 control point is available.

The block adjustment without control points with GPS-values determined in relation to the reference station in 25km distance is causing mainly a shift of the ground coordinates. The relative accuracy (one ground point in relation to another) is much better with $SX_{REL}=\pm12cm$, $SY_{REL}=\pm15cm$ and $SZ_{REL}=\pm29cm$. For distances up to a base length it is better than ±10cm.

CONCLUSION

The potential of GPS for photogrammetric applications is growing from year to year. It is today also under operational conditions possible to handle block adjustments in the accuracy range of ±20cm without control points. This requires the combination of GPS and INS and a local GPS reference station. For an on-line check of all hardware components a broadcasting reference station is required. Any failure can be seen immediately and the photo flight can be stopped or just the flight strips where problems occurred can be repeated.

The knowledge about the datum and the geoid is required, but this problem can be reduced if the reference station is located on a ground point with known national net coordinates.

ACKNOWLEDGMENT

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