DETERMINATION OF IMAGE ORIENTATION SUPPORTED BY IMU AND GPS

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ABSTRACT

For operational use, the photo orientations of a block with more than 1000 images have been determined with an LCR88 inertial measurement unit (IMU) and GPS. The relation of the IMU to the camera and corrections for the GPS-data of the projection centers have been determined and improved by means of a small reference block with 5 – 8 photos. For checking purposes the photo coordinates of 252 photos have been measured and the orientations are determined by a combined bundle block adjustment with the GPS-data of the projection centers based on 9 control points. The achieved accuracy of the photo orientations based on IMU and GPS are sufficient for the creation of orthophotos but problems are still existing with y-parallaxes in the models. The y-parallaxes can be reduced by a combined bundle block adjustment without control points or a more expensive inertial measurement system.

1. INTRODUCTION

A combined bundle block adjustment without control points is possible for a block, if a larger percentage of the projection centers are determined by relative kinematic GPS-positioning (Jacobsen 1997). In the case of a real block structure, attitude data are not required, they can be determined by the combined block adjustment with GPS-data (figure 1), that means, if at least 2 parallel flight strips are available. The flight strips may be located one beside the other or even with a vertical displacement of the flight lines (figure 2). The classical location of one flight axis beside the other has the advantage of the same photo scale, this makes the determination of tie points more easy.

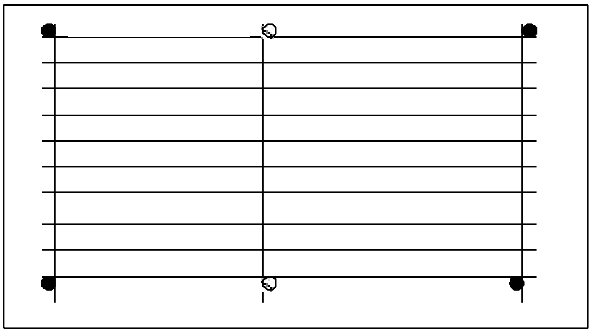


Figure 1: block configuration for combined adjustment with GPS – crossing flight strips every 20 – 30 base length or control points

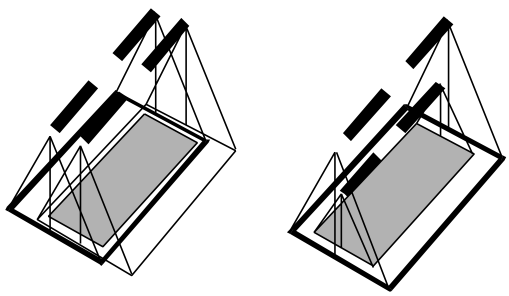


Figure 2: block configuration of linear objects – IMU-data not required

Only for a single flight strip or a combination of single flight strips (figure 3) attitude data are required in addition to GPS-coordinates of the projection centers if no control points are available, because of the problem with the lateral tilt. But even for a real block structure, the combined use of GPS and IMU in the aircraft has some advantages. In a combined computation of the positions with IMU- and GPS-data, GPS cycle slips can be determined and so the problem of shifts and drifts of the GPS-data, different from flight strip to strip can be solved.

In such a case the crossing flight strips are not directly required, but they do have the advantage of a better control of the block geometry and they are avoiding also problems of a not accurate lateral tilt of long flight strips.

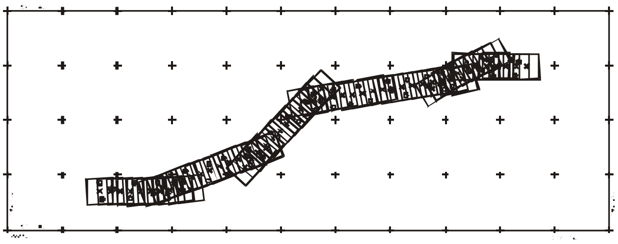


Figure 3: typical block configuration of linear objects

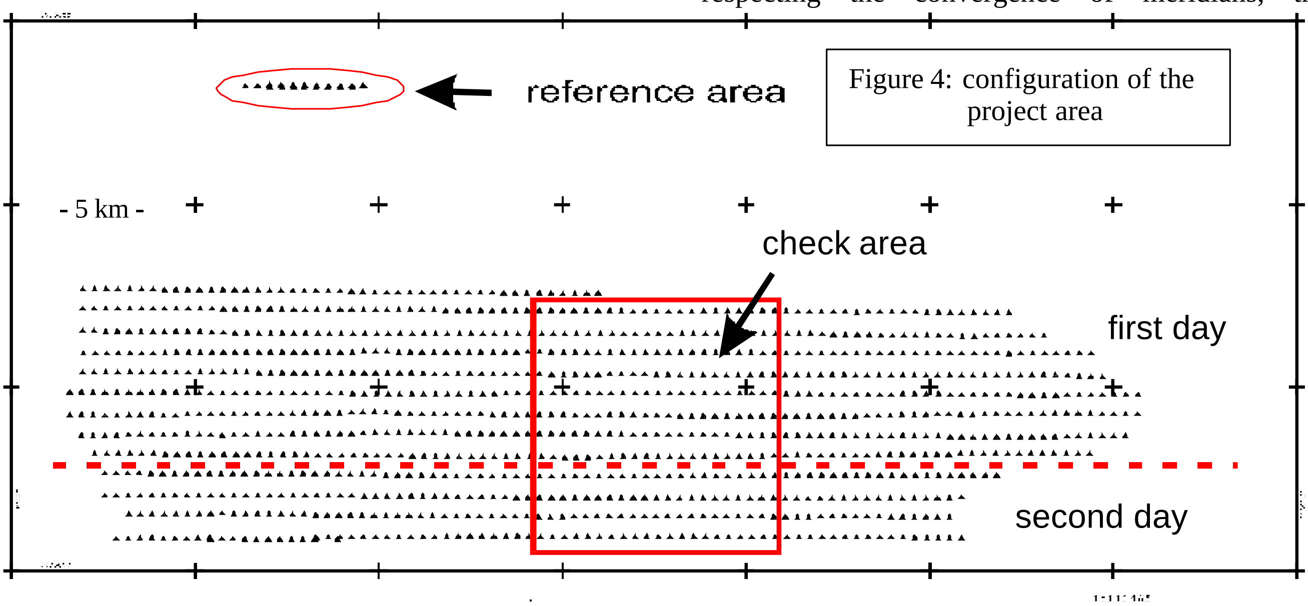
2. PROJECT

Because of a very restricted time frame for a project handled by the company BSF (Berliner Spezialflug Luftbild und Vermessungen GmbH, Diepensee) the bundle adjustment of a block with 1041 photos should be replaced by the direct determination of the photo orientations by means of relative kinematic GPS-positioning in combination with IMU. The relation between the LCR88 inertial measurement system, mounted on top of the camera and the camera itself should be determined by means of a small reference block flown before and after the project area. The large block size required a photo flight in 2 days, so the small reference block has been imaged 4 times with in total 37 photos.

The flying height of approximately 1090m above terrain corresponds with the focal length of 305mm to a photo scale 1 : 3500. The large photo scale was not required for the accuracy of the ground points but for the identification of the mapping objects.
For checking purposes a block adjustment of 252 photos (check area in figure 4) has been made, based on 9 control points. 9 control points are not sufficient for such a block of 12 flight strip without crossing lines, so a combined adjustment with coordinates of the projection centers determined by kinematic GPS-positioning was required. Of course this is not a total independent determination of the photo orientations - the same GPS-data have been used like in the determination of the orientations without control points, but the systematic GPS-data could be determined independently based on the control points in the check area.

3. PREPARATION OF THE INERTIAL DATA

The combined determination of the GPS-positions together with the attitudes, based on a LCR88, has been made by IGI, Hilchenbach by means of Kalman filtering. The conditions for the GPS-positioning was not optimal, partially only 5 satellites have been available and the PDOP was going up to 3.
As a first result only pitch, roll and yaw have been available. With the program IMUPRE of the Hannover program system BLUH this has been converted into the usual photo orientations respecting the convergence of meridians, the



different rotation definition and the dimension of the attitude data (grads instead of degrees).

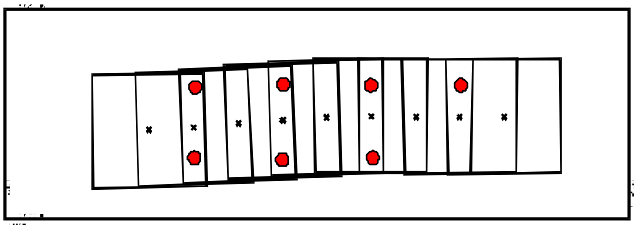


Figure 5: one of the reference blocks with control points

By a comparison of the photo orientations of the reference blocks (figure 5) with the orientations determined by means of GPS and IMU, the relation of the axis between the photogrammetric camera and the IMU has been determined as well as systematic differences of the GPS-positions. By linear time depending interpolation, based on the relation before and after the flight over the main area, the photo orientations of the images in the main area have been improved. The improvement of the attitude data was done in the pitch, roll and yaw-system, corresponding to the relation of the axes.

	roll [grads]	pitch [grads]	yaw [grads]
systematic differences day 1	-.445	-.469	.534
" day 2	-.454	-.462	.571
mean square differences			
without systematic differences day 1	.039	.012	.044
" day 2	.029	.016	.049
after linear fitting day 1	.025	.009	.007
" day 2	.021	.009	.010
after fitting by t^3 day 1	.011	.009	.007
" day 2	.021	.009	.010

Table 1: differences of the attitude data IMU – controlled bundle block adjustment (reference blocks)

Table 1 shows the differences and mean square differences between the IMU-data and the orientations determined by bundle block adjustment of the small reference blocks only based on control points. The first and last images of the reference blocks have not been taken into account because they are not so well supported by control points (see also figure 5), so approximately only 6 photos of each of the 4 control blocks have been used for comparison. A linear time depending improvement of the attitude data is required because the roll has changed both days approximately 0.070 grads between the reference area flown before and after the main area, the yaw has changed the first day 0.080 and the second day 0.100 grads. There was no significant change of the pitch.

The photo orientations determined by bundle block adjustment based on control points is not free of errors. The adjustment is giving following mean square standard deviations as mean value of all: Sphi=0.0017 grads, Somega=0.0017 grads, Skappa=0.00042 grads, SX0=0.033m, SY0=0.034m, SZ0=0.015m. But this is only the internal accuracy, it does not show the problems of the strong correlation between phi and X0 and omega and Y0.

	phi	omega	kappa	X0	Y0	Z0
phi	1.00	.03	-.06	1.00	-.03	.30
omega	.03	1.00	.08	.03	-1.00	.11
kappa	-.06	.08	1.00	-.06	-.09	-.01
X0	1.00	.03	-.06	1.00	-.03	.29
Y0	-.03	-1.00	-.09	-.03	1.00	-.11
Z0	.30	.11	-.01	.29	-.11	1.00

Table 2: correlation matrix of the photo orientations

Table 2 shows the strong correlation listed with 1.00, that means it is larger than 0.995. By this reason a complete separation between the attitude data and the projection center coordinates is not possible. It may happen that a correction of the attitude data will be made, but the differences are belonging to the GPS-data and reverse. A separation between both is only possible based on opposite flight directions or different flying altitudes (see also Jacobsen 1999).

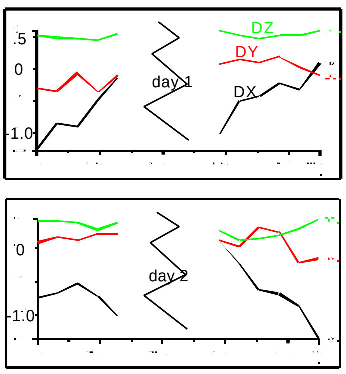


Figure 6: discrepancies in the projection centers: GPS – bundle block adjustment as a function of the time

The graphic representation of the discrepancies in the projection centers between the GPS-data and the photo orientations of the bundle block adjustments in figure 6 are showing problems of the GPS-data. The drift of the X-coordinate of the second part of the second day in the range of 1.5m is corresponding to a difference in phi of 0.078 grads. This is very exactly corresponding to a drift of phi with a size of 0.079 grads. This demonstrates the problem of the reference data, especially if a normal angle camera (f=305mm) is used. Such corresponding values cannot be seen at the other reference blocks.

4. ANALYSIS

Based on the bundle block adjustment of the check area, including photos of 12 flight strips, each with 21 images, the photo orientations based on IMU and GPS improved by means of the reference blocks have been analyzed. 9 control points are not sufficient for such a block without crossing flight strips, so a combined adjustment with GPS-data of the projection centers was necessary.

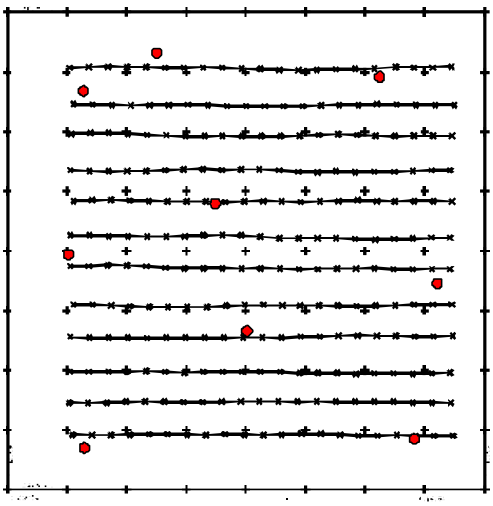


Figure 7: configuration of the check area with the control points

The mean square differences at the control points have been 3cm for X and Y and 6cm for the height, together with a sigma0 of 9 µm. Based on the control points, the improved GPS-data have been shifted 11cm in X, 15cm in Y and 59cm in the height, indicating, that the GPS-data improved by the reference blocks still do have remarkable systematic errors.

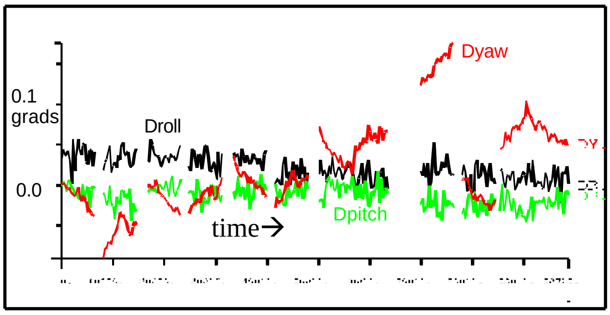


Figure 8: discrepancies of the attitude data corrected IMU – bundle block adjustment f(time)

	pitch [grads]	roll [grads]	yaw [grads]
absolute	0.028	0.020	0.059
without shift errors	0.010	0.010	0.013
linear fitting	0.010	0.010	0.007

Table 3: discrepancies of the attitude data corrected IMU – bundle block adjustment

Figure 8 and table 3 are showing the discrepancies of the attitude data between the IMU-data improved by the reference blocks and the orientations determined by bundle block adjustment and the results after elimination of constant shifts and also drifts individually for every flight strip. Especially larger differences in the yaw can be seen. The yaw has only a very small correlation to other orientation elements and it can be determined more precise than the other attitude values, that means the determined discrepancies can only be explained by the IMU-data. On the other hand the influence of errors in yaw to the image and also the object space is smaller than the influence of the other attitude data.

	X0 [m]	Y0 [m]	Z0 [m]
absolute	0.21	0.22	0.64
without shift errors	0.15	0.13	0.05
linear fitting	0.16	0.14	0.05

Table 4: discrepancies of the projection centers corrected GPS-data – bundle block adjustment

The discrepancies at the projection center coordinates between the GPS-data corrected by the reference blocks and the results of the bundle block adjustment of the check area are corresponding to the discrepancies determined by the combined block adjustment itself. Especially the discrepancies in Z0 are obvious.

More important than the discrepancy of the individual orientation components are the discrepancies at the ground coordinates determined with the improved photo orientations. With the photo coordinates and the photo orientations determined by GPS and IMU a combined intersection has been computed (iteration 0 of program system BLUH) and the resulting ground coordinates have been compared with the results of the controlled bundle block adjustment.

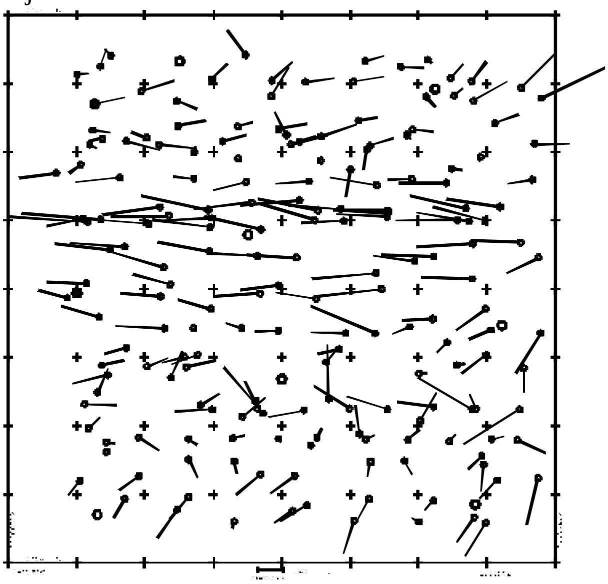


Figure 9: discrepancies at the ground coordinates X, Y RMSX=0.42m RMSY=0.18m

The discrepancies at the ground coordinates shown in figure 9 (only 10% of the 1886 points are plotted) are within the project specifications. Changing systematic errors can be seen, but the relative accuracy is still better.

	X [m]	Y [m]	Z [m]
RMS of absolute differences	0.42	0.18	0.85
systematic differences	-0.18	0.01	-0.59
RMS without systematic differences	0.38	0.18	0.61
relative accuracy (<500m)	0.19	0.10	0.36

Table 5: discrepancies at the ground coordinates

As it can be seen in figure 10 and also in table 5, the discrepancies of the Z-components of the ground points are dominated by systematic errors. But also if the overall systematic error of –0.59m is respected, the root mean square differences are only reduced to 0.61m. For a comparison with the X and Y-component, the height to base relation of 3.2 has to be respected, that means, the value of 0.61m corresponds to 0.19m and this is still in the range of the X- and Y-component.

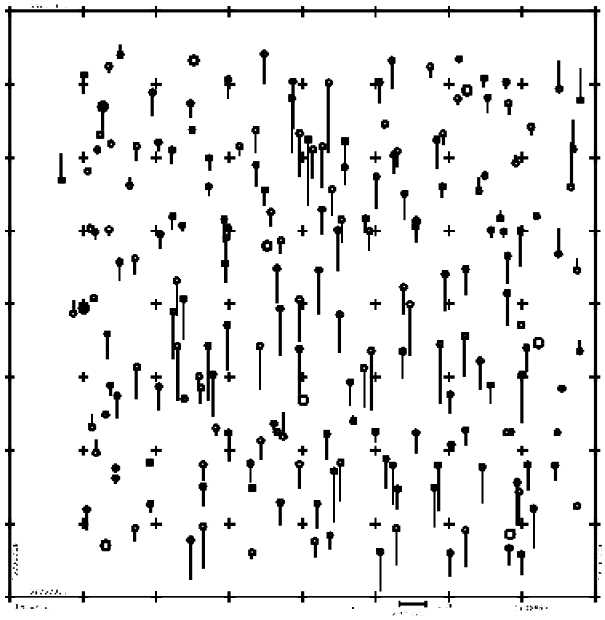


Figure 10: discrepancies at the ground coordinates Z - plot of 10% of the 1886 points

The absolute differences of the ground coordinates are important for the creation of orthophotos. For the setup of models, the y-parallax is more important. If the y-parallax is reaching the size of the floating mark, usually in the range of 30µm, the operator is getting problems with the stereoscopic impression of the floating mark in relation to the model. For the y-parallax only the relative accuracy of the orientations of both used photos are important. The relative accuracy of the attitude data of neighbored photos has been determined by program BLAN of program system BLUH together with the covariance function. The correlation of neighbored phi-values are c=0.81 and for omega it is c=0.57, that means, the values are strongly dependent. The relative accuracy has following values: $Sphi_{rel}$ = 0.011grads, $Somega_{rel}$= 0.010grads, $Skappa_{rel}$ = 0.005grads. For the influence to the model, these values have to be

multiplied by $\sqrt{2}$, but the influence of the reference data has to be taken out.
Just the value omega has an influence in the center of the model of tan 0.010 grads • 305mm = 53 µm, multiplied by $\sqrt{2}$ it reaching 75µm. Corresponding to this, the combined intersection of the photo orientations based on IMU- and GPS-data with the photo coordinates of the check area has had a resulting standard deviation of the photo coordinates of 105µm. Such an amount can not be accepted for a model orientation.

5. CONCLUSION

The determination of the image orientations by means of an LCR88-IMU and GPS has resulted in an accuracy of the ground coordinates of 0.42m for X, 0.18m for Y and 0.85m for Z. This was sufficient for the project. Systematic errors are existing, especially for the height.
A problem is existing with the used reference blocks, each with 9 images, required for the determination of the relation between the IMU and the photogrammetric camera, but also for a shift-correction (datum) of the projection center coordinates determined by relative kinematic GPS-positioning. The separation of the influence of the IMU and GPS is a problem especially for normal angle cameras (f=305mm). Such reference blocks have to be flown twice in opposite direction or with a different flying altitude.
The achieved image orientations are not sufficient for the setup of a model. If this is required, a more accurate IMU-system, that means a more expensive one, has to be used. But even this does not guarantee today the required quality. The best and save solution is the use of the IMU- and GPS-data in a combined bundle block adjustment. This still requires the determination of photo coordinates for the block adjustment – with automatic aero triangulation the effort is limited. A combined bundle adjustment includes also a better reliability.
The main advantage of photo orientations based on IMU- and GPS-data is the possibility to reduce the number of required control points, especially for linear objects. Without control or check points usually such results are not respected. Only for special projects in remote areas or in the coastal zone today such photo orientations are accepted without additional checking possibilities.

6. ACKNOWLEDGMENT

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7. REFERENCES

Elias, B., (1998): Bündelblockausgleichung mit INS-Daten, diploma thesis University of Hannover 1998

Jacobsen, K. (1997): Operational Block Adjustment without Control Points, ASPRS Annual Convention 1997, Seattle

Jacobsen, K. (1999): Combined Bundle Block Adjustment with Attitude Data, ASPRS Annual Convention 1999, Portland

Lee, J.O. (1996): Untersuchung von Verfahren zur kombinierten Aerotriangulation mittels integriertem GPS/INS, doctor thesis University of Hannover 1996