COMBINED BUNDLE BLOCK ADJUSTMENT VERSUS DIRECT SENSOR ORIENTATION

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Karsten Jacobsen

Institute for Photogrammetry and Engineering Surveys
University of Hannover
Nienburger Str.1
D-30167 Hannover, Germany
phone 01149 511 762 2485
FAX 01149 511 762 2483
Email: karsten@ipi.uni-hannover.de

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ABSTRACT

The determination of sensor orientations by combined bundle block adjustment with GPS-coordinates of the projection centers is a proved method in photogrammetry. In the case of a real block structure, attitude data are not required as observations. This is different for single flight strips, here a high number of control points or attitude data must be available. But also for a block of images, even with automatic aero triangulation, the determination of tie points is time consuming.

For an area, flown in 5 days, the image orientations have been determined by combined use of GPS and an inertial measurement unit (IMU). The relation between the IMU and the photogrammetric camera was determined by a small reference strip, flown every day before and after the block area. In 2 sub-blocks with 252 and 460 photos a block adjustment, based on control points, has been made for checking purposes, so the different methods of direct and indirect sensor orientation can be compared.

In another area, digital images, taken with a Kodak DCS 520, are available together with directly determined image orientations. Because of the small view angle, causing strong correlation, it was not possible to make a component calibration, only a system calibration of GPS + IMU was possible.

The achieved results of the direct image orientation are sufficient for some applications, for a model set up, the y-parallaxes cannot be tolerated. For this a combined bundle adjustment with GPS- and IMU-data is required, but this is possible without control points if the GPS-data are not affected by datum problems.

1. INTRODUCTION

The image orientation for photogrammetric data acquisition is a very important, but time consuming procedure. With a block adjustment, the number of required control points has been reduced drastically. The next step for a more economic solution was the combined bundle block adjustment with coordinates of the projection centers determined by relative kinematic GPS-positioning. This method allows the determination of the image orientation by a minimum of control points – just one in any corner of the block or even also without control points. Beside the survey of the ground coordinates of the control points, the determination of the image coordinates of the tie and control points takes a lot of time and effort. The manual measurement of tie and control points can be optimized by adequate software, but with the automatic aero triangulation, the tie points can be determined without manual measurement. The next step is now the direct determination of the image orientation with a combination of an inertial measurement unit (IMU) (formally named inertial navigation system – INS) together with a relative kinematic GPS positioning. The combined adjustment of IMU together with GPS by a Kalman filtering supports the kinematic GPS-positioning by the determination of cycle slips, happening especially during the turn around from one flight line to the next and the stabilization of the IMU-drift by GPS. As result we will get roll, pitch and yaw of the IMU and the coordinates of the GPS antenna. The axis of the IMU will not be parallel to the photogrammetric camera – this boresight misalignment has to be determined by means of a reference bundle block adjustment. The stability of the boresight misalignment has to be checked – the photogrammetric cameras have not been made for the attachment of the IMU with the sufficient accuracy. The antenna offset from the camera projection center to the antenna has to be determined. It is not sufficient to use the orientation information of the IMU for the reduction of the GPS-position from the antenna to the projection center because usually the camera will be rotated within the aircraft for the aircraft drift correction. Only if the antenna is located exactly above the camera, this will not have an influence. Otherwise the rotation of the camera against the aircraft has to be recorded.

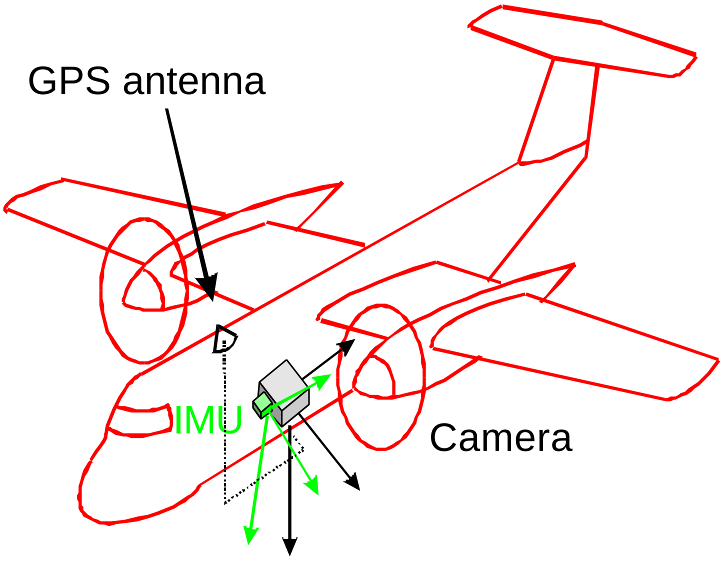


figure 1: relation of GPS-antenna and IMU
to the camera
- offset and boresight misalignment

2. PROJECTS

In cooperation with BSF (Berliner Spezialflug Luftbild und Vermessungen GmbH, Diepensee) and IGI Hilchenbach a larger block has been handled. The location of 2856 images taken in 4 flight days are shown in figure 2. Every day the misalignment and systematic GPS-position-errors have been determined before and after the flight over the main area by means of a small reference area located north of the block. In addition for checking purposes a sub-block with 252 images and another with 460 images have been determined by combined block adjustment without IMU, so more or less independent reference data are available.

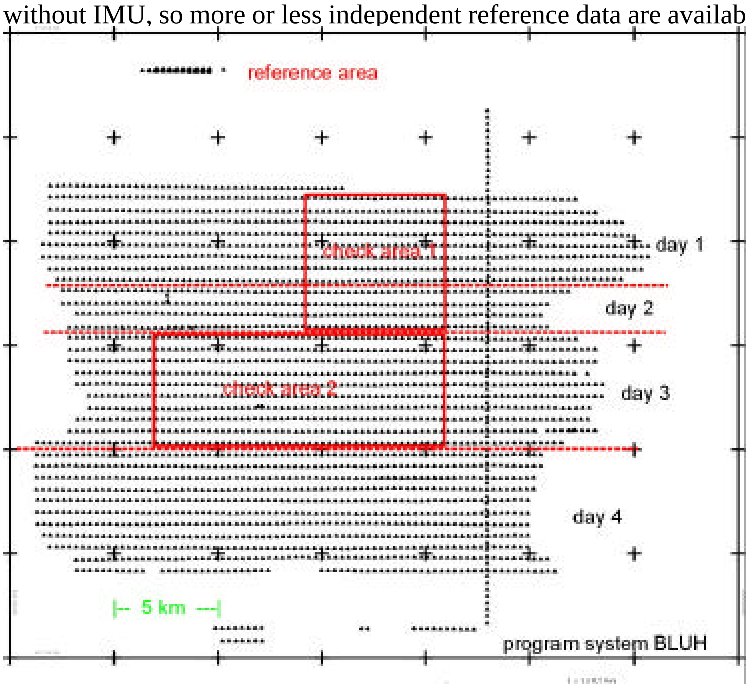


figure 2: configuration of the project
area

The inertial measurement unit LCR88 was mounted on top of a LMK 2000. An additional IMU, fixed to the aircraft, has been used for the reduction of the antenna position to the projection center. The flying height of approximately 1090m above terrain corresponds with the focal length of 305mm to a photo scale 1 : 3500. The direct orientation of a normal angle camera is more difficult than the handling of a wide angle camera, approximately the double accuracy is required for the attitude data and the determination of the misalignment is influenced by the more strong correlation of the orientation unknowns. The large photo scale in this project was required for the identification of the mapping objects and not for the accuracy. An accuracy in X and Y of +/-1m was required for the ground points corresponding to 285µm. But for a stereoscopic view the y-parallax should not exceed 30µm.

Another small block has been processed in cooperation with the University of Applied Sciences, Bochum, Germany (Bäumker et al 1999). With a self developed, fast reacting stabilized platform for carrying a digital camera Kodak 520, the sensor orientation has been determined and the camera was very close to the projected orientation.

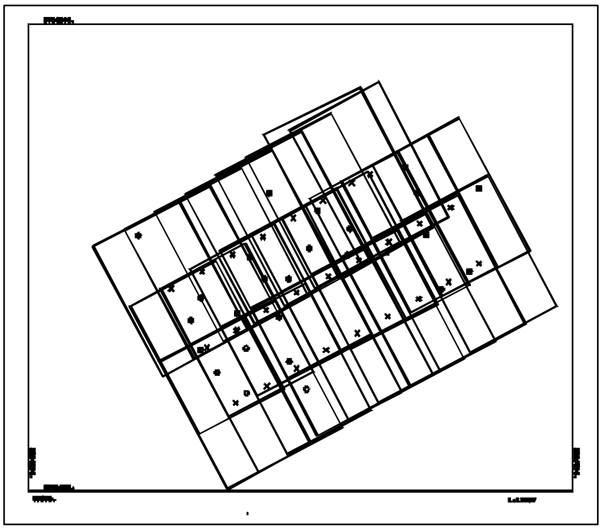


figure 3: configuration of the block flown with the fast reacting platform

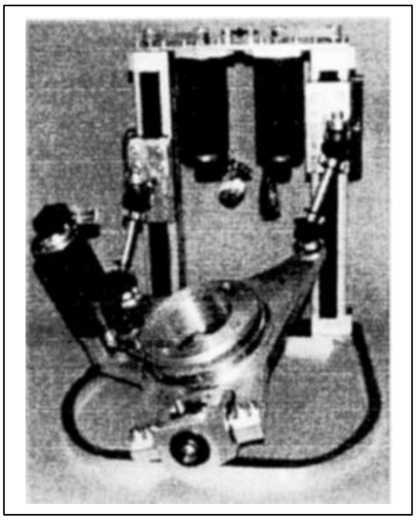


figure 4: fast reacting platform controlled by IMU

The not compensated attitudes have been recorded, so beside the close to vertical orientation of the camera, the final orientations are available. This platform includes the advantage of simplifying the creation of image maps in flat areas – no rectification, only an enlargment and horizontal rotation of the digital images is required.

DETERMINATION OF THE BORESIGHT MISALIGNMENT

Important for the direct sensor orientation is the correct determination of the misalignment between the IMU and the photogrammetric camera. The image orientation can be determined by classical bundle block adjustment based on control points. By the comparison of the sensor orientation determined by IMU and GPS with the orientations from the block adjustment, the misalignment can be determined. A direct comparison is not possible because the IMU-orientation is based on roll, pitch and yaw, with yaw as primary rotation - the image orientation in bundle block adjustment usually is based on phi, omega and kappa, with kappa as tertiary rotation. In addition yaw is oriented against North and kappa against the coordinate grid, that means the convergence of meridian has to be respected. In addition the comparison has to be made with the rotation matrix.

As mentioned before, in the case of the large test area, the misalignment has been determined every day before and after the flight over the main block area to enable also a check of a time depending change of the misalignment. The photo orientation determined by bundle block adjustment is not free of errors, especially in the case of a small view angle the orientation elements do have strong correlation’s. Especially the correlation of X0 and Y0 to phi and omega is in the range of 0.995, that means, shifts of the GPS-data and angular misalignment cannot be separated totally (Jacobsen 1999). The separation of the components can be improved by a flight over the reference area in opposite direction, but this was not done.

In general, the problem of the component separation will only have a negative influence if the flight over the main block area will be made under different conditions. In the case of the same image scale and same flight direction a separation of the components is not required. For the fast reacting platform, equipped with a Kodak DCS 520, the view angle was only 24° x 34.7°, causing a correlation up to 0.999. It was not possible to separate shifts in X0 and Y0 from roll and pitch, by this reason. After an approximate shift of the GPS-data, the projection centers have been fixed for the determination of phi and omega.

	roll [grads]	pitch [grads]	yaw [grads]
systematic differences day 1 = **boresight misalignment**	-.445	-.469	.534
" day 2	-.454	-.462	.571
" day 3	-.463	-.462	.645
" day 4	-.477	-.471	.595
mean square differences			
without systematic differences day 1	.039	.012	.044
" day 2	.029	.016	.049
" day 3	.042	.021	.117
" day 4	.034	.015	.091
after linear fitting day 1	.025	.009	.007
" day 2	.021	.009	.010
" day 3	.026	.014	.012
" day 4	.017	.016	.008
after fitting by t³ day 1	.011	.009	.007
" day 2	.021	.009	.010
" day 3	.018	.015	.011
" day 4	.018	.006	.005

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

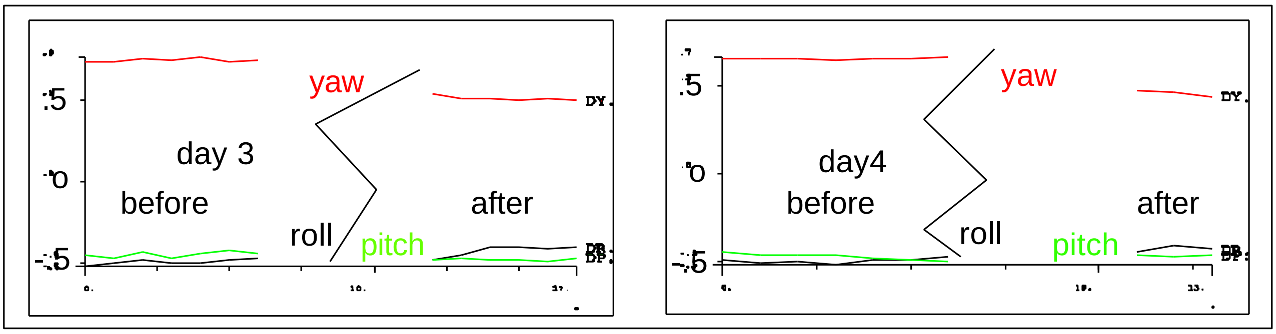
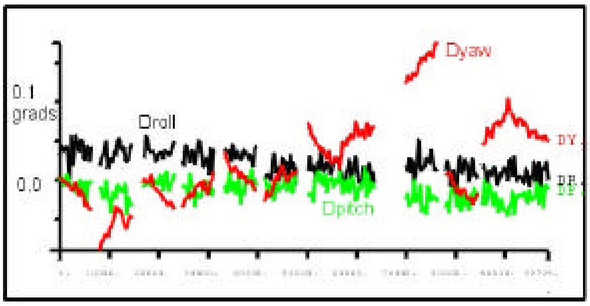


figure 5: attitude differences controlled bundle block adjustment – IMU in the reference area [grads]
= boresight misalignment

In table 1 and figure 5, the attitude differences between the controlled bundle block adjustment and the IMU-data in the reference area are shown. Within the standard deviation the misalignment in roll and pitch are constant over the 4 days, this is not the case for yaw. As it can be seen in figure 5, there is a significant change of the yaw before the flight over the reference area to after the flight over the block area in the 3rd and 4th day. If this change is a linear function of the time, it can be respected in the determination of the image orientation based on the IMU-data. The determination of the misalignment and the bundle block adjustments have been made with the Hannover program system for bundle block adjustment BLUH. In the module for the transformation of the IMU-data to photogrammetric orientation, the misalignment has been respected as linear function of the time. The same was done with the GPS-coordinates of the projection centers. The constant discrepancies (shift) of the GPS-data have been in the range of 1m. After the correction of the systematic discrepancies the mean square differences are in the range of +/- 0.2 – 0.5m for SX and SY and +/-0.2m for the height. The height is not influenced by strong correlation, so this is a realistic figure for the quality of the GPS-data.

ANALYSIS OF THE ACHIEVED RESULTS

In the both check areas, marked in figure 2, an analysis of the of the direct determined sensor orientation was possible by bundle block adjustment. The first area includes 252 images and 9 control points, the second 460 images with image coordinates determined by automatic aero triangulation and 7 control point.



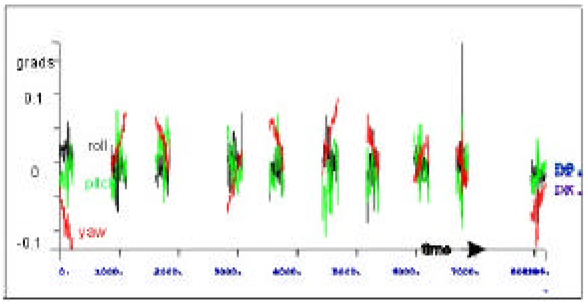


figure 6: discrepancies of attitude data check area 1 figure 7: discrepancies of attitude data check area 2

	pitch	roll	yaw	pitch	roll	yaw
	check area 1			check area 2		
absolute	0.028	0.020	0.059	0.023	0.031	0.049
without shift	0.010	0.010	0.013	0.021	0.025	0.012
linear fitting	0.010	0.010	0.007	0.022	0.023	0.009

table 2: discrepancies of the attitude data [grads] corrected IMU – bundle block adjustment

Figure 6 and 7 as well as table 2 are showing the discrepancies of the attitude data determined by direct sensor orientation (IMU improved by misalignment) against the results of the bundle block adjustment. Systematic errors are obvious, by this reason, for the analysis, the systematic components are removed individually flight strip by flight strip – this represents the results shown under “without shift” and “linear fitting”. There is no general difference between both areas. The result of the linear fitting is close to the relative accuracy (one orientation against the orientation of the neighbored image) which is important for the model setup.

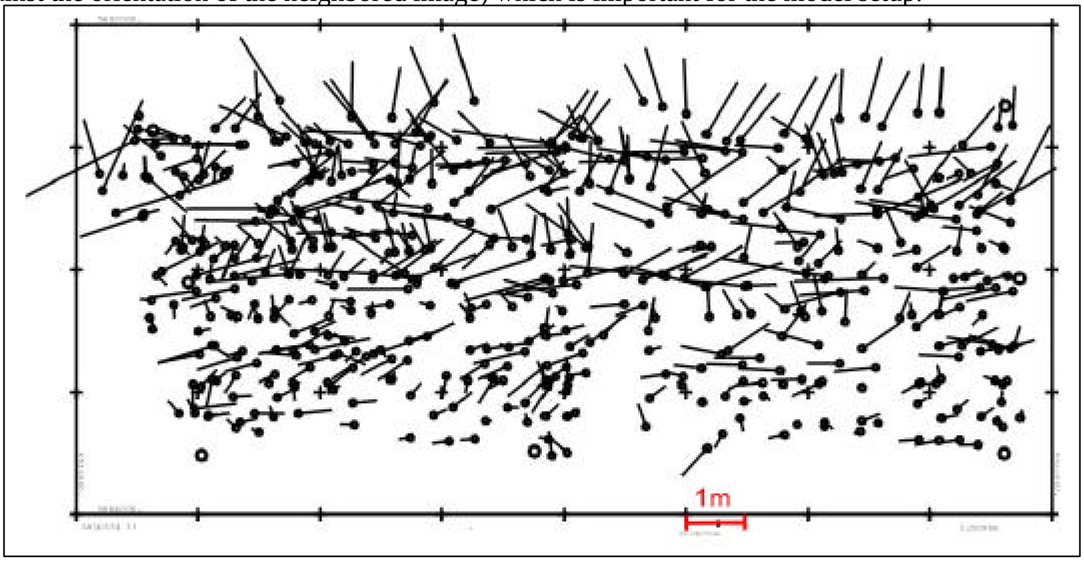


figure 8: discrepancies at the ground coordinates check area 2 SX= 0.42m, SY=0.18m
- controlled bundle block adjustment against intersection based on direct determined orientations
(plot of 1% of the 51793 ground points)

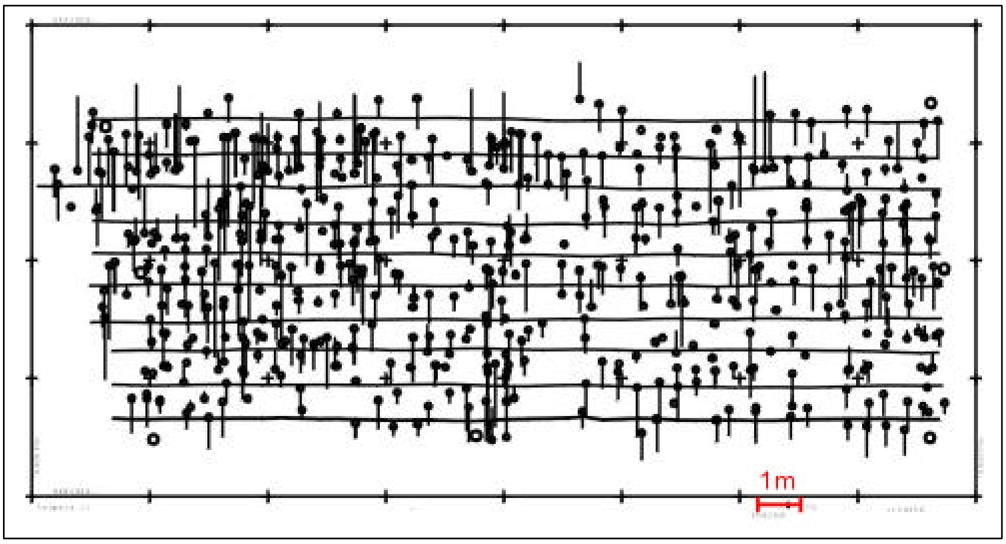


figure 9: discrepancies at the ground coordinates and flight lines check area 2 SZ = 0.85m
- controlled bundle block adjustment against intersection based on direct determined orientations
(plot of 1% of the 51793 ground points)

The results of check area 1 are similar. The check area 1 includes in total 1886 ground points. Corresponding local systematic errors are present.

	X [m]	Y [m]	Z [m]	X [m]	Y [m]	Z [m]
		check area 1			check area 2	
RMS of absolute differences	0.42	0.18	0.85	0.62	0.42	0.70
systematic differences	-0.18	0.01	-0.59	-0.12	0.22	-0.33
RMS without systematic differences	0.38	0.18	0.61	0.61	0.35	0.62

table 3: discrepancies at the ground coordinates

The lower accuracy in Z can be explained by the height-to-base-relation of 3.2 (in the case of a wide angle camera 1.6), so the accuracy in Z should be 3.2 times the accuracy in X or Y if only random errors are available.
The absolute accuracy is only one result. For the model setup the relative accuracy, represented by the y-parallax, is more important because a large y-parallax is preventing the stereoscopic view. The relative accuracy – the accuracy of a point in relation to another point in the neighborhood – for distances up to 500m is RSX=0.19m, RSY=0.10m and RSZ=0.36m. This corresponds to a mean square y-parallax of 35µm which is just at the limit of the tolerance for the model set up.
Also the neighbored orientation values are correlated, for phi the normed covariance of neighbored orientations is c=0.81, for omega c=0.57. This leads to a relative accuracy of RSphi=0.11 grads, RSomega=0.010 grads and RSkappa=0.005 grads. For the relative orientation especially omega is important. Just the value for omega is reaching 0.010 grads • focal length 305mm = 53µm, exceeding the tolerance limit for the model setup.

The small block, flown with the fast reacting platform and the digital camera Kodak DCS 520, could be checked completely by control points. A bundle block adjustment without IMU-data is resulting in a sigma0 of 0.5pixel or 0.35m on the ground. As mentioned before, it was not possible to separate the systematic GPS-errors from the misalignment, so it was necessary to fix the X0- and Y0-values. This resulted finally in a horizontal accuracy in the range of 4m sufficient for the project. The vertical accuracy is in the range of 18m and can be explained by the height to base relation of 6.

CONCLUSION

The direct determination of the sensor orientation by relative kinematic GPS-positioning together with the use of an IMU Litef LCR88 has resulted in mean square errors of the horizontal coordinate components in the range of +/-0.43m and +/-0.78m for Z. This was sufficient for the project. Remaining systematic errors are indicating a higher accuracy of neighbored points. But nevertheless there are problems with the model setup. The y-parallaxes cannot be accepted.. The discrepancies are not only caused by the IMU, also the GPS-data do have a not negligible influence. The accuracy and also the systematic errors in kappa (yaw) are exceeding the values for phi and omega (roll and pitch). This may be caused also by the photogrammetric camera. The lens cone of the LMK 2000 is only fixed to the camera body by one pin – small kappa rotations cannot be avoided. In general the photogrammetric cameras have not been constructed for the accurate attachment of the IMU, limiting the system accuracy.
The conditions are better for wide angle cameras and more precise IMU than the used LCR88, but also in corresponding projects problems with the model setup are reported. A safe solution for the model setup is the combined adjustment of the direct determined sensor orientation together with image coordinates of tie points. The tie points can be determined by automatic aero triangulation – this method is simplified by the high quality of the approximate image orientation available from IMU.
Under operational conditions at least one check point should be used in the project area to allow a check of the orientation data together with all the datum problems of the GPS-values. Even the combined adjustment with IMU- and GPS-data together with photo coordinates of tie points may be an improvement of the economic situation of the sensor orientation because the number of expensive ground control points can be reduced to an absolute minimum.

The determination of the boresight misalignment of narrow angle cameras like the used Kodak DCS 520 is causing problems. If no flight in opposite directions over a reference area is available, the influence of systematic GPS-errors cannot be separated from the components of the misalignment.

ACKNOWLEDGEMENT

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