INVESTIGATION OF DIRECT SENSOR ORIENTATION FOR DEM GENERATION

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ABSTRACT

The direct sensor orientation based on the combination of an inertial measurement system (IMU) and relative kinematic GPS-positioning has reached a high accuracy potential. By this reason it can be used not only for the generation of ortho images, but also for the georeferencing of models for the generation of digital elevation models (DEM). With the data set of the test 'Integrated Sensor Orientation' of the European Organization for Experimental Photogrammetric Research (OEEPE), the generation of DEM's has been investigated. The reached ground accuracy is in the range of ~ 10cm for X and Y, and ~ 10 - 20cm for Z is sufficient for several applications. A mayor problem are y-parallaxes appearing in the set up of the models which has been investigated in detail. This can be reduced by a combined adjustment of the image orientations from direct sensor orientation together with image coordinates of tie points, but without control points. The effect of remaining orientation discrepancies to the model orientation and the resulting model deformation was analyzed.

1. INTRODUCTION

The determination of exterior orientation parameters is a key element for any kind of imagery from terrestrial, airborne or satellite based sensors. This orientation task traditionally is solved in photogrammetry indirectly by aerial triangulation. GPS supported aerial triangulation is a well investigated and standard tool today (Ackermann F., 1992; Ackermann F. and Schade H., 1993; Jacobsen K., 1993; Colomina I., 1993). Based on GPS derived projection center coordinates, tie points, only few ground control points and its image coordinates, the exterior orientation parameters of the block can be determined by combined bundle block adjustment (GPS AT). The requirement for ground control points is significantly reduced, but still necessary for the calibration, detection and elimination of the effect of GPS cycle slips, for reliability purposes and for datum transformation. With the availability of accurate Inertial Measurement Units (IMU), this situation changed. The direct determination of the full exterior orientation (X_0, Y_0, Z_0 and ?, f, ?) became possible.

Direct sensor orientation can be described as the determination of the sensor orientation parameters based on GPS/IMU data respecting including the determination of the geometric information of the used sensor (e.g. sensor calibration). Based on the direct georeferencing, object coordinates corresponding to measured image points are determined. Two to three orthogonal mounted gyroscopes and three accelerometers are the components of an IMU. In some publication, the term inertial navigation system (INS) is used. INS contains an IMU as a measurement device as well as positioning and guidance functions (Colomina I., 1999). Inertial navigation systems were at first developed for military navigation applications in 1968. During the 1970s, the surveying community realised that INS or GPS/INS can be used as a survey instrument. In the late 1980s and early 1990s experimental studies have been done by the Ohio State University and the University of Calgary (for details, see Scherzinger B. M., 2001). In resent years, a series of tests, pilot projects and several publications confirmed the accuracy performance of direct georeferencing and integrated sensor orientations (Schwarz K.P. at al., 1993; Schwarz K.P., 1995; Skaloud J. et al., 1996; Jacobsen K., 1999; Colomina I., 1999; Cramer M., 1999; Skaloud J. 1999; Heipke C. et al., 2001; Mostafa M.M.R., Schwarz K.P., 2001). The test and pilot project results have confirmed the accuracy performance of direct georeferencing and integrated sensor orientations. The resulting orientations are sufficient for the generation of orthophotos and other applications with limited accuracy requirements. The reliability of direct georeferencing results and sometimes large y-parallaxes are week points of the direct sensor orientation (Heipke C. et al., 2001; Jacobsen K., Wegmann H., 2001).

In the following, the problem of remaining y-parallaxes based on direct sensor orientation and the effect of remaining orientation discrepancies to model deformations is analysed and respected for the DEM generation using the data set of the 'Integrated Sensor Orientation' of the European Organization for Experimental Photogrammetric Research (OEEPE).

2. GPS/IMU SENSOR INTEGRATION

The direct georeferencing is based on an integration of relative kinematic GPS positioning and IMU data by Kalman filter. An

IMU is a combination of orthogonal mounted gyroscopes and accelerometers. Different types of gyros have been used as components of an IMU such as ring laser gyros (RLG), fiber optic gyros (FOG) and dry tuned gyros (DTG) (see Skaloud J., 2002). Today fiber optic gyros are preferred.

GPS and IMU together should be considered as an integrated system so that without one of them satisfying results cannot be obtained. IMU provides a very high relative accuracy for position, velocity and attitude information over a short period. The absolute accuracy decreases depending upon the time, if no external update measurements are available. GPS can meet these requirements. The high short term stability of IMU is used to smooth observation noise of GPS. The predicted IMU positioning and velocity helps the GPS receiver for detecting carrier phase cycle slips. On the other hand GPS exhibits high long term stability and therefore its observation is appropriate to compensate the systematic and time depending IMU error effects.

2.1 System Calibration

The complete system calibration is much more important for the direct georeferencing than for the traditional indirect method (aerial triangulation). GPS/IMU provides the direct determination of the projection center position and attitude data at the instant of imaging. In the case of block adjustment the exterior orientation parameters are indirectly interpolated based on the ground control points. With direct sensor orientation, the ground coordinates are extrapolated from projection centers. Because of this, the modelling of inner orientation of imaging sensor is of major importance. Any discrepancies between the assumed mathematical model and the true physical reality during the image exposure will cause errors in object space.

Since the GPS positioning sensor (GPS antenna) and the IMU do not have the same location like the projection center in object space (entrance node) the displacement vectors have to be respected. The body frame b is defined by the sensor axes of the IMU. Similarly, a mis-orientation matrix R_p^b exists between body frame b and imaging sensor p. This positional and attitude offset has to be taken into account to obtain the orientation parameters of the camera projection center.

The boresight misalignment - the relation between the IMU and the imaging sensor (photogrammetric camera) - has to be determined by bundle block adjustment using a calibration flight over a test area. During the calibration process, 3 shifts and 3 misalignment angles are estimated in the bundle block adjustment. Corrections of the focal length and principal point coordinates can be adjusted, if a calibration flight will be done in different height levels (Jacobsen K., and Wegmann H., 2001).

2.2 Combined Intersection

Based on the image orientations determined by direct georeferencing, ground coordinates can be computed by intersection. The main problem of direct georeferencing is the missing reliability. Using check point in the project area, an accuracy analysis and quality control of direct georeferencing is possible.

Stereo plotting can be a problem in some cases with stereo models having large y-parallaxes. Large y-parallaxes sometimes are another weak point of direct georeferencing. This parallax problem can be solved by integrated sensor orientation (GPS/IMU-AT). Integrated sensor orientation in other words combined adjustment, is based on direct georeferencing together with image coordinates of tie points without using ground control points.

3. PERFORMANCE OF DIRECT GEOREFERENCING FOR DEM GENERATION

The goals of many photorammetric projects are stereo plotting, orthophoto generation and automatic digital elevation model (DEM) generation from stereo models. In the traditional way, the model orientation is based on a bundle block adjustment. Stereo plotting is not always possible because of remaining y-parallaxes using direct georeferencing orientations. For the generation of orthophotos, accuracy performance of direct georeferencing is sufficient (Heipke at al., 2001). The main objective of this presentation is the investigation of accuracy performance of direct georeferencing for automatic DEM generation.

Digital elevation models have become an indispensable source of Geographical Information Systems (GIS), which is playing a vital role in urban and town planning and decision making. The automatic DEM generation is possible today by using automatic image matching techniques (Yastikli N., 2002). Some of image matching programs are operating in the image space (e.g. DPCOR, Institute for Photogrammetry and GeoInformation, University of Hannover), that means, remaining y-parallaxes do not affect the image matching algorithm. The remaining y-parallaxes can be seen by the mismatch of the intersection for the computation of the ground coordinates of matched points using the exterior orientation parameters.

3.1 Used Data Set

The empirical investigations have been carried out with the data of the OEEPE-test “Integrated Sensor Orientation” (Heipke C. et al., 2001). The test field in Fredrikstad, Norway, has been flown using the POS/AV 510-DG of Applanix (M. Mostafa at al., 2001) and separately AEROcontrol IIb of IGI mbH. 51 targeted and well distributed ground control points are available in test field with an accuracy better than 0.01m for all coordinate components. For this OEEPE test, calibration flights are available in two different scales (1:5.000 and 1:10.000). The actual test flights have been flown with wide angle aerial cameras in the scale 1 : 5000. The calibration flights in two different scales and the configuration of the actual test flights based on the POS/AV 510-DG are presented in Figure 1 and Figure 2

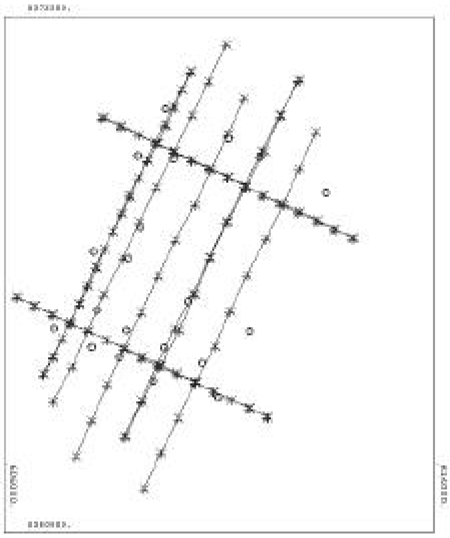

Figure 1. Flight axes of calibration flight, 1:5.000+1:10.000

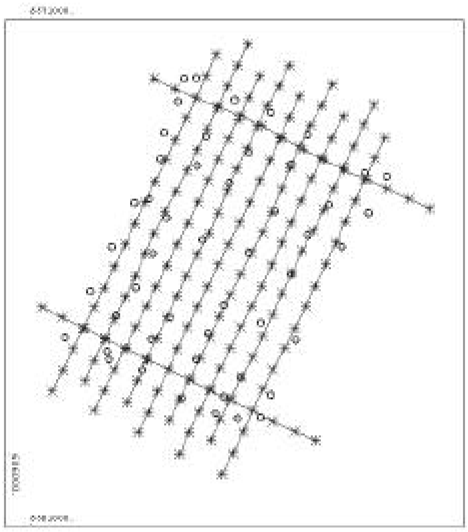

Figure 2. Flight axes of test flight, 1:5.000

3.2 Boresight Misalignment

The boresight misalignment, the relation between the IMU and the photogrammetric camera, has been determined together with the actual interior orientation based on bundle block adjustment using the calibration flights (1:5.000+1:10.000) over the test area. The actual focal length and the location of principal point were determined by self calibration with additional parameters using the Hannover program system BLUH. The focal length correction is Δf = 39 µm and the improvement of the principal point Δx = -24 µm and Δy=1µm. The image orientation determined by the calibration flight with the improved focal length and principal point were used as reference for the determination of the misalignment (Table 1.) However, the photogrammetric orientation is not free of error, there is a strong correlation between X_0 and phi and Y_0 and omega or transformed to pitch and roll (Jacobsen K., 1999). The difference between the transformed photogrammetric orientation and the IMU data is the boresight misalignment. Using the boresight misalignment (3 shift values and 3 rotations) the GPS/IMU data was improved.

Approach	control points	σ_0 [µm]	RMS of control points [cm]		
			X	Y	Z
GPS AT	20	6.07	2.6	4.1	4.6
GPS AT with corrected f and principal point.	20	5.97	2.6	2.3	3.2

Table 1. Results of reference bundle block adjustment

3.3 Combined Adjustment

The object coordinates of measured image points, were intersected based on GPS/IMU data improved by the boresight misalignment (direct georeferencing). For accuracy assessment, independent check points were used. Without using any control points, GPS/IMU data improved by boresight misalignment and image coordinates of tie point with the improved focal length and the principal point were adjusted together for the integrated sensor orientation purposes (GPS/IMU-AT) with the Hannover program system BLUH. For comparison, traditional bundle block adjustment (AT) and GPS supported bundle block adjustment (GPS AT) have been made using the test flight data (Figure 2.) with the improved focal length and principal point. Table 2 depicts the results of AT and GPS AT. Table 3 depicts the results of direct georeferencing and integrated sensor orientation.

Approach	Con. point	σ_0 [µm]	RMS of control points [cm]		
			X	Y	Z
AT	49	5.49	2.1	1.7	4.5
GPS AT	49	6.19	2.9	2.6	5.4

Table 2. Results of AT and GPS AT using test flight

Approach	Con. Po.	σ_0 [µm]	RMS differences at check points [cm]		
			X	Y	Z
Direct georeferencing	0	19.20	6.2	4.0	8.2
Integ. Sensor Orien.	0	6.55	3.3	2.4	6.9

Table 3. Results of direct georeferencing and integrated sensor orientation (GPS/IMU AT) (Applanix data set)

4. DEM GENERATION

The direct georeferencing results (Table 3.) are larger by a factor 2-3 compared to traditional bundle block adjustment. As mentioned before, one of the major problems of direct georeferencing are remaining y-parallaxes of the stereo models. The y-parallaxes are not identical to σ_o of the combined intersection. The relative orientations for all models (170 models) were computed based on both direct georeferencing and integrated sensor orientation using test flight (Figure 3). Table 4 also depicts σ_o from the table 3, the average of the RMS y-parallaxes per model, called $\sigma_{o,rel}$ and percentages of models with RMS y-parallaxes larger than 10 and 20 µm.

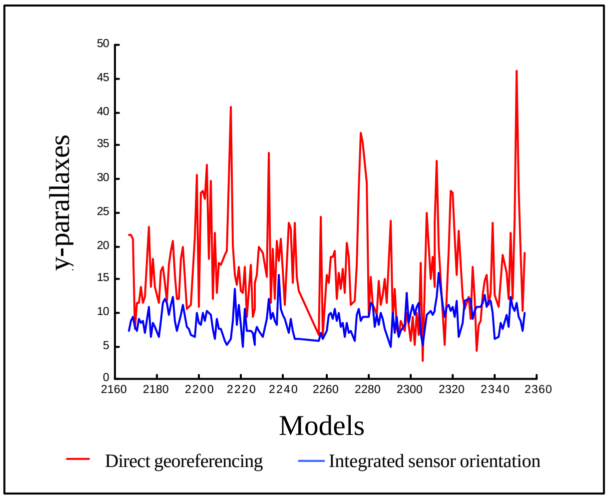

Figure 3. RMS y-parallaxes per model based on direct georeferencing and integrated sensor orientation

Approach	s_0 [µm]	$s_{0,rel}$ [µm]	RMS y-parallaxes	
			>10 µm	>20 µm
direct georeferencing	19.2	18.2	147	41
integrated sensor orientation	6.55	9.2	49	-

Table 4. σ_o and number of models exceeding shown limits of RMS y-parallaxes

Stereo models were selected according to different y-parallax classes; in order to investigate the influence of remaining orientation discrepancies to the model orientation and to analyze model deformations for DEM generation from stereo images (Figure 4).

For the analysis of the influences of model orientation errors to the ground coordinates, a synthetic DEM with 50m spacing has been generated for selected models. For each selected model, image coordinates of these points were computed based on the traditional aerial triangulation.

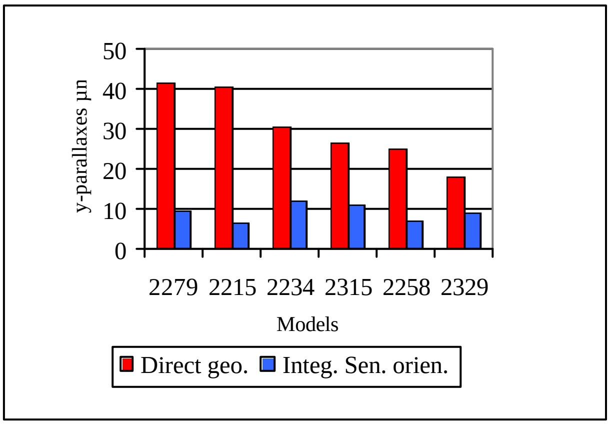

Figure 4. RMS y-parallaxes of selected stereo models based on direct georeferencing and integrated sensor orientation (GPS/IMU AT)

The object coordinates of these synthetic DEM points were computed using the orientation parameters based on:

- GPS supported aerial triangulation (GPS AT)
- direct georeferencing (GPS/IMU)
- integrated sensor orientation (GPS/IMU AT)

By comparison of the object coordinates of the synthetic DEM-points with the computed object coordinates based on the different orientation parameters, the influence of the y-parallaxes to the model orientation were investigated and model deformations were analysed. Figure 5 and Figure 6 are showing the influence of the orientation discrepancies to the model orientation. The object coordinates of synthetic DEM points were compared to the computed object coordinates using different orientation parameters (direct georeferencing and integrated sensor orientation) and the differences are shown in figures 7 and 8.

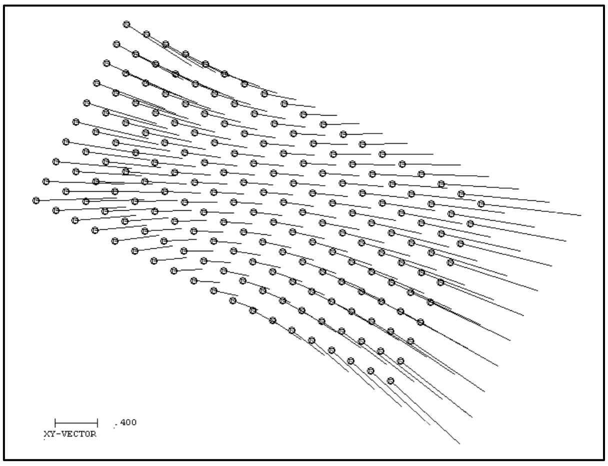

Figure 5. Influence of the orientation discrepancies to the ground coordinates X, Y of model 2279/2278 using direct georeferencing orientations

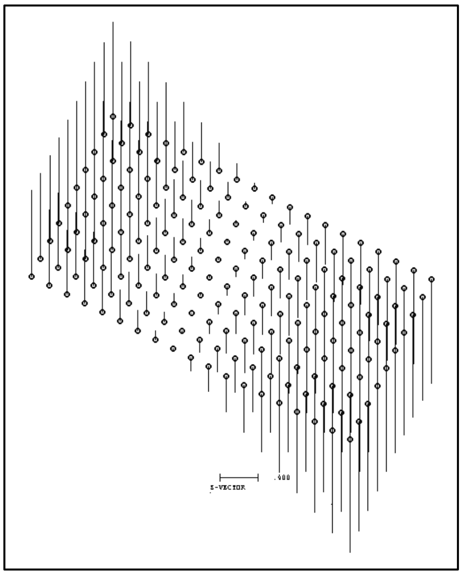

Figure 6. Influence of the orientation discrepancies to the ground coordinates of model 2279/2278 in Z plane using direct georeferencing orientations

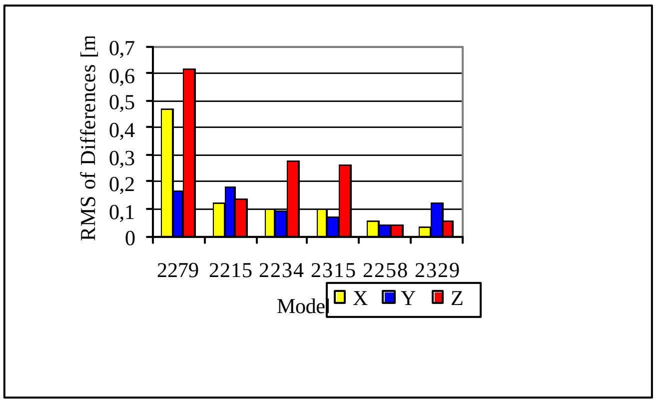

Figure 7. RMS of differences at ground coordinates using direct georeferencing orientations

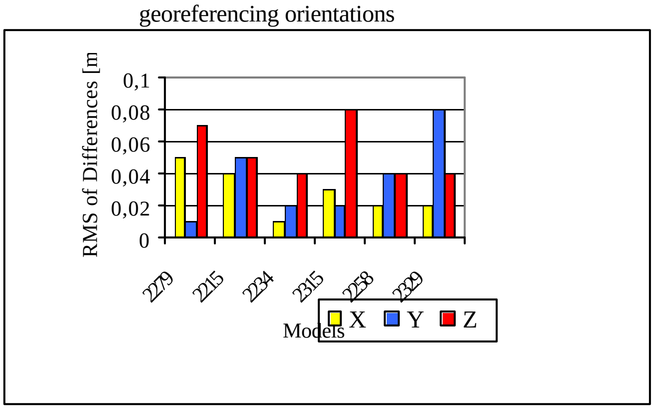

Figure 8. RMS of differences at ground coordinates using GPS/IMU AT orientations

In some models based on direct georeferencing the RMS y-parallaxes are exceeding 30 µm (see figure 3), most of them are the first or last two images of a flight strip. This may be explained with a loss of satellite connection during the turn around from one flight strip to the next. In traditional photogrammetric flights very often additional photographs are taken in front of the start and after the end of each strip. The influence of corresponding orientation problems to the model orientation can be seen in Figure 6. The figures 5 and 6 do show the influence of orientation discrepancies to the ground coordinates in one model. For the integrated sensor orientation approach, there is no problem for the DEM generation and even stereo plotting. RMS y-parallaxes are not exceeding 15 µm (figure 3) and the influence of orientation discrepancies is quite limited compared to the direct georeferencing (figure 8).

There is no generally accepted rule about the expected accuracy of DEM's. The accuracy of a DEM is specified by the vertical quality of DEM points. Depending upon the grid size of DEM's standard deviations for Z of 1/20th (for flat terrain) to 1/10th (for rougher terrain) of the linear grid size is a suitable approach for the required accuracy of DEM's (Ackermann F., 1996). For 10 m grid spacing, it corresponds to SZ=0.5m for flat terrain and 1m for rougher terrain. Based on investigations using the data set of the test 'Integrated Sensor Orientation' of the European Organization for Experimental Photogrammetric Research (OEEPE), the direct sensor orientation and integrated sensor orientation can be used for large scale DEM generation. Integrated sensor orientation can be used for precise DEM generation and also stereo plotting.

5. CONCLUSIONS

The direct sensor orientation based on the combination of an inertial measurement system (IMU) and relative kinematic GPS-positioning has reached a high accuracy potential. This accuracy potential allows us to use direct georeferencing for the generation of orthophotos and other application with not extreme accuracy requirements.

Stereo plotting is not always possible because of remaining y-parallaxes using direct georeferencing orientations. The automatic DEM generation can be based on precise image matching techniques. Some image matching program do operate in the image space (e.g. DPCOR), that means, remaining y-parallaxes do not affect the image matching algorithm itself. The influence of remaining orientation discrepancies can be seen at the ground coordinates of matched points computed by intersection using the exterior orientation parameters.

Within this investigation, the influence of remaining orientation problems to model deformations was analysed for purposes of DEM generation based on selected stereo models of the data set 'Integrated Sensor Orientation' of the OEEPE. It has been shown that the direct georeferencing can be used for automatic DEM generation purposes. Using the integrated sensor orientation approach by an adjustment of the GPS/IMU-orientations together with tie points, the y-parallax problem can be solved. The model set up for stereo plotting and precise DEM generation from stereo models are possible using the integrated sensor orientation.

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