THE EFFECT OF SYSTEM CALIBRATION ON DIRECT SENSOR ORIENTATION

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ABSTRACT

The determination of image orientation parameters of any sensor during data acquisition became possible by combined use of an inertial measurement system (IMU) and GPS. In this integrated system, GPS antenna, IMU and imaging sensor are located different position in airborne carrier. Because of this reason, the displacement vectors between sensors have to be determined. Similarly, axes of the IMU and imaging sensor are not same and a mis-orientation matrix exists between them. System calibration is including both calibration of individual sensor and calibration between sensors. The IMU calibration for drifts and biases and the calibration of imaging sensor for interior orientation parameter are components of sensor calibration. Calibration between sensors contains the determination of a constant displacement vector between sensors and a constant mis-orientation matrix between IMU body frame and imaging sensor frame. The boresight misalignment, the relation between the IMU and the imaging sensor is determined by bundle block adjustment using a calibration flight. The small change of correction of interior orientation and 3 shifts and 3 misalignment angles between IMU and imaging sensor directly affect direct sensor orientation.

In this study, the effects of the system calibration on direct sensor orientation is investigated based on data set of the test ‘Integrated Sensor Orientation’ of the European Organization for Experimental Photogrammetric Research. For this, bundle block adjustments have been done with different approach using calibration flights. Using these bundle block adjustments, correction for interior orientation and 3 shifts and 3 misalignment angles between IMU and imaging sensor have been determined. The object coordinates of measured image points have been intersected based on GPS/IMU data improved by the boresight misalignment. For each approach, computed checkpoints coordinates have been compared with given reference coordinates. The effect of system calibration on direct sensor orientation has been analyzed comparing results of different georeferencing results using different system calibration parameters.

1. INTRODUCTION

The image orientation is a key element for any kind of imagery from terrestrial, airborne or satellite based sensors. Traditionally, this task is solved indirectly by using bundle block adjustment in photogrammetry. Today, GPS supported aerial triangulation is successfully used many photogrammetric map production projects. For new sensors such as LIDAR, SAR sensor and CCD line cameras, this indirect method can not be used because of the requirement of exterior orientation parameters for each scan line (Schwardz at all, 1993). The direct measurement of image orientations during image acquisition is appropriate solutions for these sensors using GPS/IMU system. By combined use of GPS and IMU (Inertial Measurement Unit), the direct measurement of exterior orientation parameters (X_0, Y_0, Z_0 and ω, φ, κ) of any sensor became possible. The GPS/IMU integrated system also can be used traditional field where bundle block adjustment is used.

The georeferencing of images, recorded by different sensor can be defined as a transformation problem. For traditional photogrammetric cameras, this problem cover transformation form the image coordinates in camera coordinate frame to the mapping frame. To the georeferencing aerial images, the interior and exterior orientation parameters have to be determined. In this context, direct sensor orientation can be described as the determination of the sensor orientation parameters based on GPS/IMU data respecting 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.

The direct sensor orientation is based on GPS and IMU data integrated with Kalman Filter. Three orthogonal mounted gyroscopes and three accelerometers are the components of an IMU. In some publication, the term inertial navigation system (INS) is used instead of IMU. INS contains an IMU as a measurement device as well as positioning and guidance functions (Colomina, 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 integrated system 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 at al., 1993; Schwarz, 1995; Skaloud et al., 1996; Jacobsen, 1999; Colomina, 1999; Cramer, 1999; Skaloud 1999; Heipke et al., 2001; Mostafa and Schwarz, 2001).

In the following, the effect of system calibration on direct sensor orientation and not correct data handling are investigated based on the data set of the test ‘Integrated Sensor Orientation’ of the European Organization for Experimental Photogrammetric Research (OEEPE).

2. SYSTEM CALIBRATION

The system calibration is important task for direct sensor orientation. In direct sensor orientation, the GPS/IMU measure the true physical imaging sensor position, velocity and attitude when imaging sensor recording the images. The exterior orientation parameters are determined by interpolation based on the ground control points in indirect method. In the case of direct sensor orientation, the exterior orientation parameters are measured directly and object points coordinates are extrapolated from projection centers. Because of this, the modelings of interior geometry of imaging sensor and the relation between sensors have major importance.

The system calibration is the first steps of direct or integrated sensor orientation. It includes the determination of the attitude relation and shifts between the IMU and the imaging sensor (boresight misalignment), GPS antenna offsets and time synchronization errors as well as the interior orientation of imaging sensor. The system calibration is cover calibration of all sensors and calibration between sensors (Skaloud, 1999). The calibration of sensors is include the calibration of imaging sensor, IMU calibration for shift and drift parameters and GPS antenna multipath calibration etc. The calibration between sensors is contain the determination of GPS antenna offset, positional and attitude offset between the imaging sensor frame and IMU body frame.

The interior orientation parameters of imaging sensor are determined by laboratory calibration but in flight condition these parameters can be differs from actual parameters. GPS and IMU calibration are performed after production. These calibration parameters can be checked also in the integration process of GPS and IMU measurement by Kalman Filtering (see for detail Schwarz at. al., 1994). The offset between GPS antenna and imaging sensor is measured with standard surveying methods. The determination of the boresight misalignment is a more difficult task. The coordinate axes of imaging sensor are not parallel to the IMU body frame and the attitude relation between the IMU body frame and the imaging sensor frame can not be measured directly. Because of this, the boresight misalignment, the relation between the IMU and the imaging sensor, is determined by comparison of the GPS/IMU derived sensor orientation parameters with the orientation of bundle block adjustment. During system calibration, correct mathematical model also important to obtain optimal solution.

2.1 Coordinate System

The national coordinate system is used for bundle block adjustment and traditional photogrammetric data handling. These coordinate systems are not orthogonal and do not correspond to the correct mathematical model used in photogrammetry. The difference between correct mathematical model and curved earth cause vertical deformation. This deformation is compensated by earth curvature correction of the image coordinates in traditional approach.

The national coordinate systems are mixed coordinate systems. The horizontal coordinates are belonging to map projection and vertical coordinates are generally orthometric heights. The horizontal coordinates of map projections have scale factor and this scale factor causes affinity deformation (Jacobsen at al., 1999). The image orientation in direct sensor orientation is based on directly measured exterior orientation by GPS/IMU. The scale factor of notational net has influence on to the flying height and this influence has to be taken into account.

2.2 The Calibration of Imaging Sensor

The interior orientation parameters of imaging sensor are determined in laboratories under constant and homogenous temperature conditions. Under actual flight conditions, the temperature is colder than laboratory condition. This temperature change is cause a lens deformation. Meier (1978) investigated the focal length change of Zeiss cameras as a result of lens deformation depending upon flying height. The change of the focal length corresponds to the change of scale factor for the height. Because of this, the determination of interior orientation parameters has mayor importance for direct sensor orientation. The situation is similar also for the location of the principal point.

2.3 Boresight Misalignment

Using GPS/IMU integrated system, position is measured by GPS antenna and attitude is measured by IMU system during image exposure by imaging sensor. For direct sensor orientation, the relation between sensors has to be determined precisely. GPS antenna offset is measured by conventional survey method. The boresight misalignment, the relation between IMU and imaging sensor can not be measured directly (Figure 1). The attitude and shift relationship of IMU body frame and imaging sensor frame is determined by comparison of the GPS/IMU derived sensor orientation parameters with the results of bundle block adjustment of reference block. The IMU generates roll, pitch, and yaw as attitude information. The IMU attitude information is related to geographic north while photogrammetric orientation phi, omega and kappa are related to grid north. The convergence of meridian has to be taken into consideration for transformation from IMU orientation to photogrammetric orientation (Jacobsen, 1999).

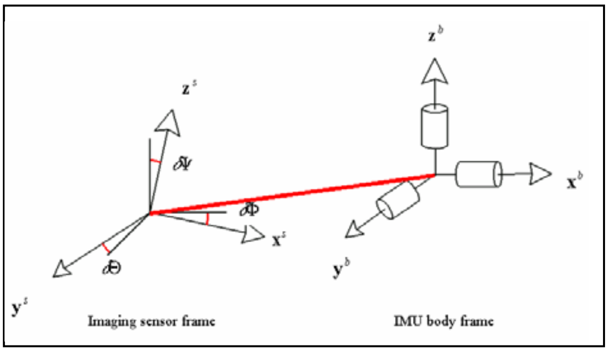

Figure 1. The relation between IMU and imaging sensor

3. THE EFFECT OF SYSTEM CALIBRATION

The effect of system calibration on direct sensor orientation is investigated using the data set of the OEEPE test “Integrated Sensor Orientation” (Heipke et al., 2001). The test field in Fredrikstad, Norway, is about 5 x 6 km^2 and has 51 well distributed signalized control points with UTM/EUREF89 coordinates and ellipsoidal heights was used for the OEEPE test. The accuracy of used signalized control points in test field is better then 0.01 m.

The calibration flights in two different scales (1:5.000 and 1:10.000) were flown over reference area for system calibration. The actual test flights were flown in the scale 1:5000 over test field. The calibration flight and test flight were carried out with photogrammetric camera, Ashtech GPS receiver and the Applanix POS/AV 510 system (see for detail Nilsen, 2002). The flight pattern of calibration flight and test flight can be seen in Figure 2 and Figure 3.

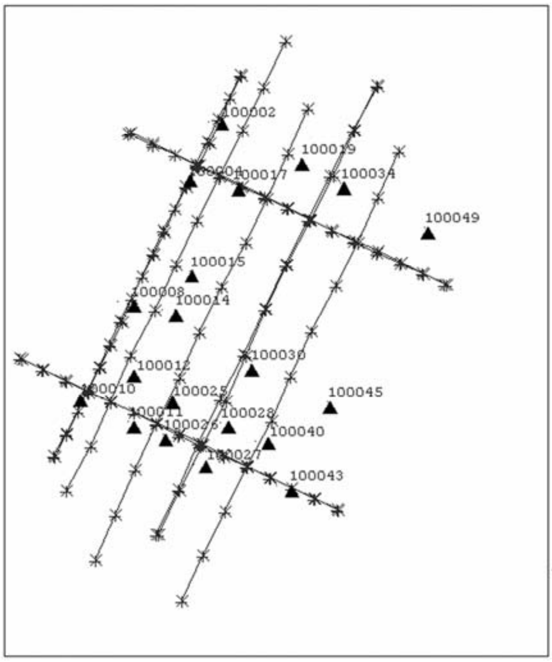

Figure 2. Flight axes of calibration flight, 1:5.000+1:10.000

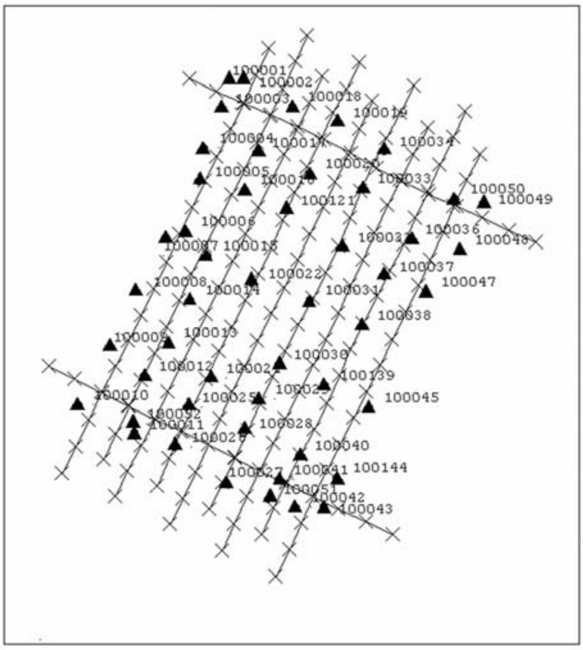

Figure 3. Flight axes of test flight, 1:5.000

The system calibration parameters were computed with different approaches, to investigate the effect of system calibration on direct sensor orientation. The bundle block adjustments with calibration flights in the two different scales (1:5.000 and 1:10.000) have been made in the UTM system and the orthogonal tangential system for each approach. The approaches followed in bundle block adjustment can be described as below:

a) GPS supported bundle block adjustment,
b) GPS supported bundle block adjustment, with self calibration by additional parameters,
c) GPS supported bundle block adjustment, using corrected interior orientation parameters with self calibration by additional parameters.

At first, the interior orientation parameters from camera calibration certificate f=153.344 mm were used for bundle block adjustment. The correction for focal length Δf = 0.039 mm and the principal points Δx_0 = -0,024 mm, Δy_0 = 0.001 mm were computed in second approach with self calibration by additional parameters in UTM system. In tangential system, computed correction are different for focal length Δf = 0.039 mm and the principal points Δx_0 = -0,024 mm, Δy_0 = 0.001 mm. This difference can be explained the scaling effect of UTM system. The corrected interior orientation parameters have been used in third approach. The results of these adjustments using the Hannover program system BLUH can be seen in Table 1.

Approach	Cont. points	σ_0 [μm]	RMS of control points [cm]		
			X	Y	Z
GPS sup. bun. bl. adj. in UTM	20	12.02	8.2	6.5	25.8
GPS sup. bun. bl. adj. in TAN.	20	8.93	3.0	2.6	10.4
GPS sup. bun. bl. adj. in UTM with self cal. par.	20	6.58	1.5	2.5	3.0
GPS sup. bun. bl. adj. in TAN. with self cal. par.	20	6.45	1.4	2.7	2.8
GPS sup. bun. bl. adj. in UTM with self cal. par. and cor. f, x_0, y_0.	20	5.97	2.6	2.3	3.2
GPS sup. bun. bl. adj. in TAN. with self cal. par. and cor. f, x_0, y_0	20	5.67	2.3	2.4	3.6

Table 1. Results of reference bundle block adjustment

The influence of actual interior orientation parameters can be seen by comparing the results of the first and third approaches in Table 1. The boresight misalignments are determined by comparing the GPS/IMU derived exterior orientation parameters with the exterior orientation parameters from reference bundle block adjustments for each approach. The GPS/IMU derived attitudes and positions of test flight were improved by the different sets of boresight misalignment. The improved GPS/IMU derived attitudes were converted into the photogrammetric definition of rotations.

The object coordinates of measured image point and check points were intersected based on GPS/IMU derived exterior orientation parameters improved by boresight misalignment. The object coordinates of check points computed by intersection and compared with the given reference coordinates. The results of combined intersection using different system calibration parameters can be seen in Table 2.

Approach	Check.	σ_0	RMS of check points [cm]

	points	[μm]	X	Y	Z
System cal. from app. a in UTM	49	21.20	7.1	4.9	28.5
System cal. from app. a in TAN.	49	21.20	7.1	5.0	12.2
System cal. from app. c in UTM	49	24.54	6.1	8.5	19.4
System cal. from app. c in TAN.	49	25.4	7.7	10.0	9.4
System cal. from app. c in UTM with corrected f, x_0, y_0	49	20.6	6.6	4.0	8.6
System cal. from app. c in TAN. with corrected f, x_0, y_0	49	18.03	6.7	4.6	8.7

Table 2. Results of combined intersection using different system calibration parameters

In Table 2, from line 1 to line 4 interior orientation parameters from calibration certificate were used. In line 1 and line 2, boresight misalignment from approach a bundle block adjustment were used. From line 3 to line 6, boresight misalignments from approach c bundle block adjustment were used. The results of combined intersections in tangential system are better then UTM system because of the scaling effect of UTM system. In last two lines in Table 2, boresight misalignment from approach c and corrected interior orientation parameters were used. The effect of interior orientation on direct sensor orientation can be seen comparing the results of combined intersection in line 3 and line 5 or line 4 and line 6 especially in Z. The results of combined intersection in last two lines are approximately same in UTM system and tangential system using optimal system calibration parameters.

4. CONCLUSIONS

The direct georeferencing is extrapolation from image projection center ground surface. Because of this, it is sensitive for system calibration and precise data handling. The system calibration is cover the determination of boresight misalignment, GPS antenna offsets and time synchronization errors as well as the actual interior orientation of imaging sensor. The individual sensor calibration is done after production and also some parameters can be checked integration process of GPS and IMU measurement. GPS antenna offset is measured by conventional survey method.

The determination of boresight misalignment is major importance in direct sensor orientation because it defines the relation between IMU and imaging sensor. Any discrepancies or a systematic error in this definition is cause error in object space. Similarly actual interior orientation parameter of imaging sensor is directly effect the direct sensor orientation since the chance of focal length corresponds to scale factor for height. The national coordinate system is used many map production projects but do not orthogonal coordinal system. The national coordinate system has scale factor and this scale factor causes affinity deformation. The boresight misalignment and actual interior orientation parameters can be determined by using calibration flight over reference area in two different scales. If the local scale chance is respected by change of focal length, the data handling can be done directly in national coordinate system.

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