INFLUENCE OF TIE POINT DISTRIBUTION ON INTEGRATED SENSOR ORIENTATION

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ABSTRACT:

Direct measurement of exterior orientation parameters has been a challenge in photogrammetry for many years. Direct sensor orientation using a calibrated GPS/IMU system can potentially eliminate the need for ground control points and aerial triangulation, and consequently, result in a great reduction in the cost and time of aerial photogrammetry. Previous studies have shown that, comparing to conventional aerial triangulation, direct sensor orientation yields larger errors in image and object space. It has also been shown that including a number of tie points within an integrated orientation approach can result in a reduction of errors in image space. In this paper the influence of the number and distribution of tie points on integrated orientation is investigated. Experiments with various numbers of tie points regularly as well as randomly distributed are presented. Results indicate that an increase in the number of tie points up to one point per model results in a considerable reduction of the mean error in image space.

1. INTRODUCTION

Ground control survey and aerial triangulation are the most costly and time-consuming stages in most photogrammetric mapping projects. Direct measurement of exterior orientation parameters by a thoroughly calibrated GPS/IMU system can potentially eliminate the need for ground control points and aerial triangulation, and consequently, result in a great reduction in the cost and time of aerial photogrammetry. With direct measurement of the position and attitude of the camera perspective center at exposure times, object space coordinates of image points can be computed using a least-squares forward intersection. This method is referred to as direct sensor orientation (Cramer and Stallmann, 2001; Yastikli and Jacobsen, 2005a).

While direct sensor orientation seems to reduce the photogrammetric mapping process to photography and stereo plotting, in practice the accuracy of attitude parameters directly measured with the current technology of IMUs is generally lower than that of conventional photogrammetry. Previous experiments with commercially available GPS/IMU systems have shown that direct sensor orientation in the scale of 1:5000 reaches accuracies that are two to three times lower when compared to the results of conventional aerial triangulation (Heipke et al., 2002; Khoshelham et al., 2007).

An alternative approach to determining sensor orientation parameters and transforming image-space coordinates to object space is integrated sensor orientation (Ip, 2005; Jacobsen, 2004). In this approach, tie points contribute to the refinement of the exterior orientation parameters through a bundle adjustment. It has been shown that the introduction of tie points in the computations leads to a considerable improvement of the accuracy in image space (Heipke et al., 2002). Since integrated sensor orientation does not require ground control information but the image coordinates of tie points must be measured, it can be considered as a trade-off between direct sensor orientation and conventional aerial triangulation in terms of cost and speed.

An important issue in integrated sensor orientation is the number and distribution of tie points. While previous studies have shown the effect of including a certain number of tie points, it is not known how the accuracy is influenced by variations in the number and distribution of the ties. The Objective of this research is to investigate the influence of the number and distribution of tie points on the accuracy of integrated sensor orientation. We focus on the orientation of an airborne frame camera using a commercial GPS/IMU system.

The paper is structured in five sections. Section 2 describes the calibration of integrated GPS/IMU system. In section 3 the transformation of points from image space to object space through direct and integrated sensor orientation is discussed. Experiments with various numbers of tie points in integrated sensor orientation are presented in section 4. Conclusions appear in the last section.

2. CALIBRATION OF GPS/IMU FOR AIRBORNE FRAME CAMERAS

The calibration of GPS/IMU is basically a comparison of exterior orientation parameters measured directly by GPS/IMU with those obtained by using a reference method (Forlani and Pinto, 2002; Honkavaara, 2004; Yastikli and Jacobsen, 2005b). The discrepancies are modelled by computing calibration parameters that relate GPS/IMU position and attitude to the reference exterior orientation parameters. Bundle adjustment aerial triangulation is most often used as the reference method for the computation of exterior orientation parameters. Therefore, the determination of calibration parameters requires one or more test flights over a test field with signalised control points. There are two main approaches to the computation of calibration parameters: 1-step approach and 2-step approach (Heipke et al., 2002).

2.1 1-step calibration approach

In the 1-step calibration approach, a bundle adjustment of all available information in image and object space is performed. Calibration parameters are estimated in such a way that the sum of squared residuals of observations is minimized. The main calibration parameters include the three components of the lever arm distance between the GPS/IMU and the camera perspective centre and three misalignment angles that model the relative orientation of the IMU with respect to the camera. Usually the camera exposure is precisely synchronized with GPS and IMU; however, if this is not the case then a synchronization offset can be added to the set of calibration parameters. Parameters of the interior orientation of the camera can also be estimated in the calibration procedure, provided that the calibration flights are designed in a way that the effects of different parameters can be separated.

2.2 2-step calibration approach

A more straight forward way to compute the calibration parameters is to perform the aerial triangulation first, and then compare the estimated exterior orientation parameters with GPS/IMU measurements. The discrepancies between GPS/IMU measurements and the camera position and attitude parameters estimated in aerial triangulation are modelled by a polynomial function. The general form of the polynomial for position measurements is expressed as (Cramer and Stallmann, 2001):

$$\begin{bmatrix} X_{GPS/IMU} - X_C \\ Y_{GPS/IMU} - Y_C \\ Z_{GPS/IMU} - Z_C \end{bmatrix} = \sum_{i=0}^{n} \begin{bmatrix} a_i \\ b_i \\ c_i \end{bmatrix} .t^i \qquad (1)$$

and for attitude measurements:

$$\begin{bmatrix} \omega_{GPS/IMU} - \omega_C \\ \varphi_{GPS/IMU} - \varphi_C \\ \kappa_{GPS/IMU} - \kappa_C \end{bmatrix} = \sum_{i=0}^{n} \begin{bmatrix} u_i \\ v_i \\ w_i \end{bmatrix} .t^i \qquad (2)$$

where variables with *GPS/IMU* subscript denote GPS/IMU measurements, those with *C* subscript denote aerial triangulation estimate of the exterior orientation parameters, *i* subscripts denote the polynomial coefficients, *t* is time and *n* is the order of the polynomials.

The polynomial coefficients play the role of calibration parameters. A zero order polynomial incorporates only three GPS shifts and three misalignment angles. This basic set of six parameters can properly calibrate the GPS/IMU if a comparison of aerial triangulation estimate of exterior orientation parameters and GPS/IMU measurements shows discrepancies that remain within a limited constant range over time. Otherwise, a large variation of discrepancies over time indicates that additional drift parameters must be taken into account, thus a higher order of the polynomial should be used.

Transformation between different coordinate systems also requires careful attention in the calibration process. GPS/IMU attitude measurements are navigation angles, roll, pitch and yaw, which define the relative orientation of the IMU body with respect to the navigation frame. In order to be used in Equation (2), navigation angles must be converted to photogrammetric angles, omega, phi and kappa, which determine the relative orientation of the camera with respect to a 3D Cartesian object coordinate system (Figure 1). Assuming that all the computations are to be carried out in orthogonal coordinate systems, the conversion of navigation angles to photogrammetric angles involves the following sequence of rotations:

$$\mathbf{R}_C^L = \mathbf{R}_N^L \cdot \mathbf{R}_B^N \cdot \mathbf{R}_C^B \qquad (3)$$

where $\mathbf{R}_C^L$ is a rotation matrix that contains photogrammetric angles, omega, phi and kappa, and brings the camera axes parallel to object coordinate system (local frame); and $\mathbf{R}_B^N$ is the rotation from IMU body to navigation frame and contains navigation angles, roll, pitch and yaw. As Figure 1 illustrates, the rotations from camera to body frame, $\mathbf{R}_C^B$, and from navigation to local frame, $\mathbf{R}_N^L$, can be simply described with the following matrices:

$$\mathbf{R}_C^B = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \qquad \mathbf{R}_N^L = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix} \qquad (4)$$

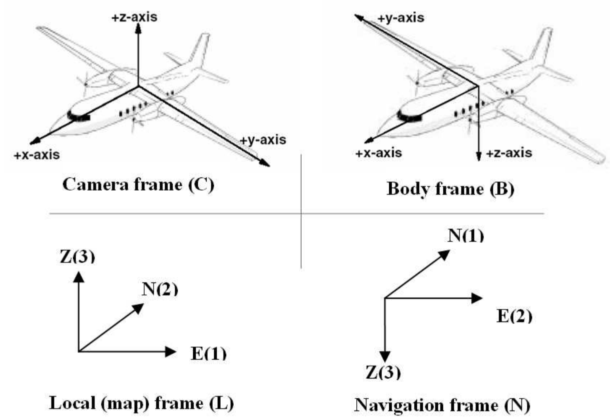

Figure 1: Coordinate systems used in navigation and photogrammetry.

3. DIRECT AND INTEGRATED ORIENTATION

Once determined, the calibration parameters are used to correct the GPS/IMU measurements of the exterior orientation parameters. In this direct orientation approach, object space coordinates of all the image points can be computed using a least-squares forward intersection procedure, with no need for ground control or tie points (Khoshelham et al., 2007). The exterior orientation parameters corrected by the calibration parameters are treated as constants in the forward intersection estimation model. In other words, no further corrections are applied to the position and attitude of the perspective centres, and only the positions of the points in image and object space are adjusted.

In the integrated orientation approach a further correction of the exterior orientation parameters of the camera is permissible. This is achieved by a simultaneous adjustment of a number of tie points within a bundle adjustment model with additional constraints for refining the exterior orientation parameters. Since every tie point appears in at least two images, integrating a number of tie points in the estimation model results in a redundancy of observations that allows for the correction of exterior orientation parameters.

The introduction of tie points in the integrated orientation approach allows one to exploit the strength of the bundles for the refinement of exterior orientation parameters. Since in the estimation model sum of the squared residuals of the image coordinates are minimized, one can expect that integrated orientation results in improved accuracy in image space, and consequently, reduced Y parallax in the stereo model.

The Assignment of suitable weights to the exterior orientation parameters is a determinant factor in the refinement of the calibrated position and attitude parameters of the camera. If the exterior orientation parameters are assigned very large weights, as compared to image coordinates, then the result of the estimation model would be very similar to that of direct orientation. In other words, the corrections to exterior orientation parameters would be very small, and the object space coordinates of the tie points would be similar to those obtained from direct orientation. On the other hand, if the exterior orientation parameters are assigned weights that are too small, then large corrections would be estimated for these parameters, which may result in a greater error in the coordinates of the points in object space.

4. EXPERIMENTS AND RESULTS

To experiment with the integrated orientation approach and the influence of the tie points a test dataset acquired by Applanix integrated GPS/IMU system was used. The dataset is one of the two datasets that were distributed to the participants of the OEEPE test on integrated sensor orientation (See Nilsen, 2002). The data acquisition comprised of a calibration flight at an image scale of 1:10000, and a test flight at 1:5000 over a test field with 49 signalised control points located in Norway. The dataset consists of the following data:

- Position and attitude measurements made by GPS/IMU;
- Ground coordinates of the control points in EUREF89/UTM system with heights over the reference ellipsoid;
- Image coordinates of control points and a number of tie points.

The calibration of the system was carried out using the data of the 1:10000 flight. A bundle adjustment aerial triangulation of the image coordinates and control points was performed using PAT-B aerial triangulation software. No GPS/IMU data were introduced at this step and the exterior orientation parameters computed within the bundle adjustment were used as reference in the calibration procedure. The 2-step approach was implemented for the estimation of calibration parameters. A comparison of the camera position and attitude parameters from bundle adjustment with GPS/IMU measurements showed discrepancies that did not largely vary over time; therefore, the basic set of six calibration parameters consisting of three GPS shifts and three misalignment angles was adopted for the calibration.

For the experiments with direct and integrated orientation the data of the 1:5000 flight were used. A bundle adjustment aerial triangulation of these data was performed so that the results can serve as reference for the evaluation of direct and integrated orientation approaches. The data of the bundle adjustment included the ground coordinates of 13 control points evenly distributed in the block. No control points were introduced in the computations of direct and integrated orientation. Computed ground coordinates for 18 check points were used to evaluate the accuracy of bundle adjustment as well as direct and integrated orientation approaches in object space. Figure 2 depicts the perspective centres of a total of 181 photographs taken at the scale 1:5000 along with the control and check points.

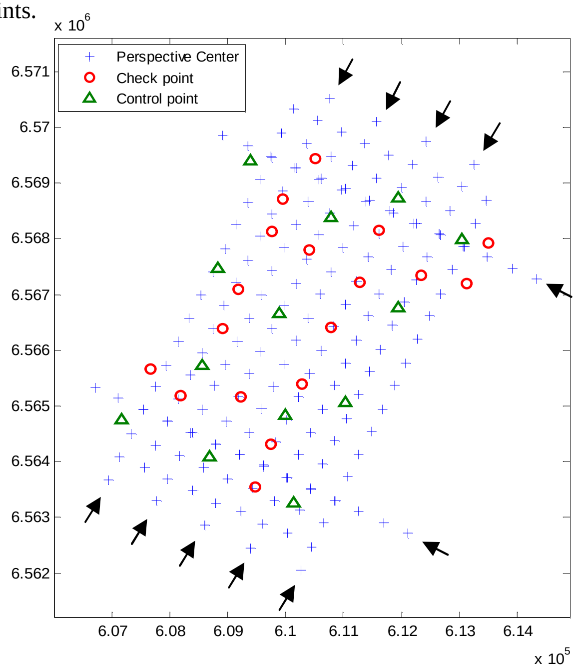

Figure 2. Perspective centers of the images of 1:5000 flight along with the control and check points. Arrows indicate the direction of the flights.

To investigate the influence of tie points, ground coordinates of the check points were computed using different methods with various numbers of tie points. Obviously, all tie points contribute in the bundle adjustment aerial triangulation, and no tie points are introduced in the direct orientation approach. In the integrated orientation approach seven schemes for the selection of the tie points were designed. Table 1 summarises the tie point selection schemes. In addition, for each selection scheme two distribution schemes were taken into account. In the regular distribution scheme an even distribution of the tie points across the block was desired; whereas, in the random distribution scheme, a number of tie points equal to the corresponding regular distribution scheme but randomly distributed within the block was selected. For example, in the selection scheme S-1 with regular distribution a tie point at the centre of the overlapping area of every pair of consecutive images was selected, which resulted in 190 tie points evenly distributed across the block. Thus, in the selection scheme S-1 with random distribution, 190 tie points at random positions within the block were selected. In the selection schemes S-2 and S-4 with regular distribution tie points in symmetric von Gruber positions were chosen.

The accuracy in object space was evaluated by the RMSE of the discrepancies between measured and computed ground coordinates of the check points. Figure 3 shows these discrepancies for S-1, S-2 and S-4 tie point selection schemes with both regular and random distribution. In image space, the mean residual of the image coordinates of the tie points was used as an indicator of the accuracy. Table 2 summarises the accuracies obtained by including various numbers of tie points with regular distribution in integrated orientation. Results of using the random distribution scheme are presented in Table 3. Results of bundle adjustment aerial triangulation and direct orientation are also included in Table 2 and Table 3 for the sake of comparison.

Table 1: Tie point selection schemes

Selection Scheme	Description
S-1/10	1 tie point in every 10th model
S-1/5	1 tie point in every 5th model
S-1/3	1 tie point in every 3rd model
S-1/2	1 tie point in every 2nd model
S-1	1 tie point in every model
S-2	2 tie points in every model
S-4	4 tie points in every model

A comparison of the results of direct orientation and integrated orientation in Table 2 as well as Table 3 reveals that introducing a minimum number of tie points has a minor impact on the accuracy in object space. While the RMSE values in X and Y direction obtained by integrated orientation are similar to (even worse than) those obtained by direct orientation, a slight improvement of the RMSE in the Z direction can be observed. A considerable improvement, however, can be seen in the accuracy in image space as indicated by the mean residuals. These results confirm previous findings of the OEEPE test on integrated sensor orientation (Heipke et al., 2002).

A close examination of the results in Table 2 and Table 3 also shows that the accuracies in image space exhibit a further improvement as a consequence of increasing the number of tie points; whereas, the accuracies in object space remain more or less in the same range, and are not affected by the increase in the number of tie points. The changes in the mean residual values obtained by integrated orientation indicates that by including a sufficient number of tie points in the computations the Y parallax in image space can be reduced to values that are two to three times lower than those obtained by direct orientation.

Figure 4 demonstrates the influence of the number and distribution of tie points on the accuracy of integrated orientation in image space. As can be seen, by increasing the number of tie points up to one point per model (scheme S-1) the mean residual values decrease almost linearly. The selection schemes S-2 and S-4 result in only a slight improvement of the accuracy in image space.

It is interesting to note that regular and random distributions of the tie points yield very similar results. This means that the accuracy in image space is not influenced by the distribution of the tie points. One exception to this conclusion is the scheme S-4, where the mean residual associated with random distribution is noticeably smaller than that of regular distribution. A possible explanation for this could be that the accidental proximity of the tie points in random distribution can bias the mean residual to a smaller value.

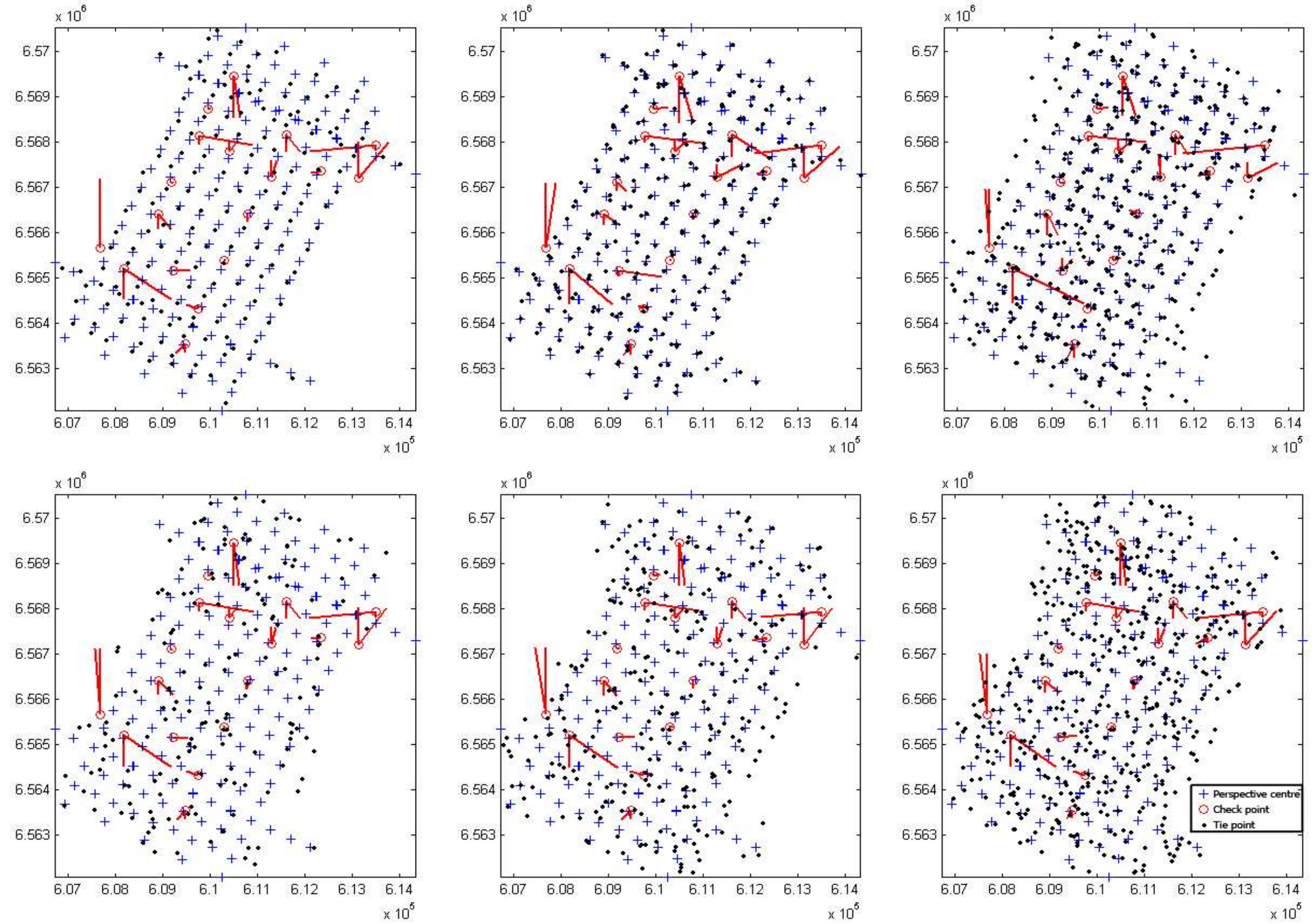

Figure 3. Vectors of error in check points obtained by using various tie point selection and distribution schemes in integrated orientation. Top row: regular distribution; button row: random distribution; from left to right: selection schemes S-1, S-2 and S-3.

Table 2: Results of using various numbers of tie points with regular distribution in integrated orientation

Method	Scheme	Nr. of tie points	RMSE_X (cm)	RMSE_Y (cm)	RMSE_Z (cm)	Mean Residual (µm)
Bundle AT	-	2294	3.3	3.5	10.5	4.1
Direct Orientation	0	-	6.7	7.7	14.7	36.19
Integrated Orientation	S-1/10-Reg	17	7.6	7.5	12.2	26.2
	S-1/5-Reg	33	7.6	7.5	12.2	23.2
	S-1/3-Reg	58	7.6	7.6	12.2	20.1
	S-1/2-Reg	87	7.8	7.6	12.2	18.5
	S-1-Reg	172	7.7	7.4	11.9	15.0
	S-2-Reg	296	7.9	7.5	11.6	12.6
	S-4-Reg	516	8.4	7.0	11.9	13.1

Table 3: Results of using various numbers of tie points with random distribution in integrated orientation

Method	Scheme	Nr. of tie points	RMSE_X (cm)	RMSE_Y (cm)	RMSE_Z (cm)	Mean Residual (µm)
Bundle AT	-	2294	3.3	3.5	10.5	4.1
Direct Orientation	0	-	6.7	7.7	14.7	36.19
Integrated Orientation	S-1/10-Rand	17	7.5	7.4	12.0	25.5
	S-1/5-Rand	33	7.5	7.2	12.0	23.4
	S-1/3-Rand	58	7.6	7.3	12.1	20.2
	S-1/2-Rand	87	7.6	7.6	12.1	18.2
	S-1-Rand	172	7.7	7.4	12.5	14.1
	S-2-Rand	296	7.6	7.4	12.2	12.4
	S-4-Rand	516	7.6	7.0	12.3	11.1

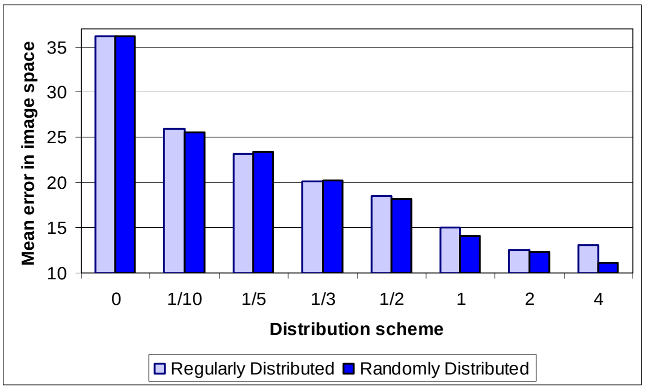

Figure 4. Mean error values in image space obtained for various selection and distribution schemes.

5. CONCLUSIONS

In this paper the influence of the number and distribution of tie points on integrated orientation of an aerial frame camera was investigated. The integrated orientation approach was implemented through a bundle adjustment of a number of tie points with additional constraints for refining the exterior orientation parameters. The number of tie points varied across experiments from 17 (one point in every 10th model, selection scheme S-1/10) to 516 (one point in each model, selection scheme S-4). Experiments were also conducted with regularly distributed tie points as well as randomly distributed ones. It was found that including tie points in integrated orientation approach, regardless of their number and distribution, does not substantially improve the accuracy in object space, and the results are similar to those obtained by direct orientation approach. In image space, however, it was shown that an increase in the number of tie points up to one point per model results in a considerable reduction of the mean residual of the image coordinates. This suggests that including a minimum of one tie point per model can be recommended for practical applications since it leads to a considerable reduction of Y parallax in image space. Also, it was shown that regular and random distributions of the tie points result in a similar range of errors in image space. Therefore, it can be concluded that the distribution of the tie points does not have an influence on the accuracy of integrated orientation approach in image space.

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REFERENCES

Cramer, M. and Stallmann, D., 2001. On the use of GPS/inertial exterior orientation parameters in airborne photogrammetry, ISPRS Workshop "High Resolution Mapping from Space 2001", Hannover, Germany, pp. 32-44.

Forlani, G. and Pinto, L., 2002. Integrated INS/DGPS systems: calibration and combined block adjustment, Proceedings of the OEEPE Workshop: Integrated Sensor Orientation, Institute for Photogrammetry and Geoinformation, University of Hannover, Hannover, Germany, pp. 85-96.

Heipke, C., Jacobsen, K. and Wegmann, H., 2002. Analysis of the results of the OEEPE test "Integrated Sensor Orientation", Proceedings of the OEEPE Workshop: Integrated Sensor Orientation, Institute for Photogrammetry and Geoinformation, University of Hannover, Hannover, Germany, pp. 31-49.

Honkavaara, E., 2004. Calibration in direct georeferencing: Theoretical considerations and practical results. Photogrammetric Engineering and Remote Sensing, 70(11): 1207-1208.

Ip, A.W.L., 2005. Analysis of integrated sensor orientation for aerial mapping. MSc Thesis, University of Calgary, Calgary, 181 pp.

Jacobsen, K., 2004. Direct/integrated sensor orientation - pros and cons, XX ISPRS Congress, Commission III, Istanbul, Turkey, pp. 829-835.

Khoshelham, K., Saadatseresht, M. and Milan, A., 2007. Calibration of integrated GPS/INS system and direct sensor orientation, Geomatic '86 annual conference, National Cartographic Centre, Tehran, Iran.

Yastikli, N. and Jacobsen, K., 2005a. Direct sensor orientation for large scale mapping - potential, problems, solutions. Photogrammetric Record, 20(111): 274-284.

Yastikli, N. and Jacobsen, K., 2005b. Influence of system calibration on direct sensor orientation. Photogrammetric Engineering and Remote Sensing, 71(5): 629-633.