ACCURACY ASSESSMENT OF ADS40 IMAGERY OVER THE PAVIA TESTSITE

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ABSTRACT

The particular sensor geometry of the airborne Three-Line-Scanner (TLS) brings complexity into the triangulation process. A specialization of the methods and algorithms is therefore required. A modified bundle adjustment algorithm with the possibility of using three different trajectory models and self-calibration has been developed at the Institute of Geodesy and Photogrammetry (IGP), ETH Zurich.

The ADS40 camera of Leica Geosystems, Heerbrugg is a commercial example of an airborne TLS sensor. The Orima software, which is marketed by the camera vendor, includes specialized tools for the triangulation and the self-calibration of the ADS40 images.

The main goals of this study are to investigate the geometric accuracy potential of the ADS40 camera under different network configurations and with different camera and trajectory models. The ADS40 images acquired over the Pavia test site in Italy is used to achieve these goals. Two image blocks with 2000 m and 4000 m flying heights have been processed and compared by the research groups at the Geomatics Laboratory, University of Pavia and the IGP, ETH Zurich. The results of both datasets are presented in this paper, with the main focus on the 4000 m flight.

1. INTRODUCTION

1.1 Background

The Linear Array CCD sensors have been introduced into the field of aerial photogrammetry almost a decade ago. The first commercial line scanner ADS40 was developed by LH Systems jointly with the DLR (Sandau et al., 2000). At the same time, Starlabo Corporation, Tokyo designed the airborne Three-Line-Scanner (TLS) system, jointly with the University of Tokyo (Murai and Matsumoto, 2000). The system was later called STARIMAGER.

For the triangulation of the TLS imagery, a modified bundle adjustment algorithm based on the collinearity equations has been developed at the IGP, ETH Zurich. It includes as options three different types of trajectory models (Gruen and Zhang, 2003): *(a)* Direct georeferencing model with stochastic exterior orientations (DGR), *(b)* Piecewise Polynomials with kinematic model up to second order and stochastic first and second order constraints (PPM) and *(c)* Lagrange Polynomials with variable orientation fixes (LIM). These models are used for the improvement of the exterior orientation parameters (EOP), which are measured by the GPS/IMU. A number of ground control points (GCPs) are needed for this approach in order to achieve high accuracies. In addition, the self-calibration capability has been added to the sensor model using basically a set of 18 additional parameters (APs) to model the systematic errors of the camera and tested in two different testfields (Kocaman et al., 2006).

The Orima approach to the triangulation problem uses the orientation fixes concept. The algorithmic details are given in Hinsken et al. (2002). When compared to the LIM of the IGP, ETH Zurich, the models are similar in terms of estimating the EOP at the orientation fixes. A self-calibration model, originally developed for frame cameras, was adapted for the ADS40 sensor and is currently available in Orima (Tempelmann et al., 2003).

The triangulation approaches of ETH Zurich and the Orima software have been tested in the past using the ADS40 dataset acquired over the Vaihingen/Enz testfield. The accuracy results of both approaches are almost identical when self-calibration is applied. They correspond to 0.22 and 0.38 pixels in planimetry and height, respectively. For more details see Cramer (2007).

1.2 The Datasets

The Pavia test site has been established by the Geomatics Laboratory, University of Pavia. A number of signalized and natural GCPs have been added to the site. Three different ADS40 test flights over the Pavia testfield have been performed in 2004 in a joint project with the CGR Company, Italy. 7 ADS40 strips were taken at three different flight altitudes (2000 m, 4000 m, and 6000 m). The staggered-array functionality was switched off and only one line was acquired for the backward and forward views. In this paper, triangulation results of the 2000 m and 4000 m image blocks are presented. Figure 1 shows the strip outlines of both. The inner rectangles denote the actual processing area for triangulation. The average ground resolutions are ~20 cm and ~39 cm for the low and high flight altitudes, respectively.

Signalized GCPs with a size of 60 cm are used in this study. They are measured with a high-accuracy GPS. The red points in Figure 1 are used as control points in the tests of the 5 GCP configuration. For the 12 GCP configuration, the green points and the four red points in the corners are used. The black points are used as independent check points in all tests.

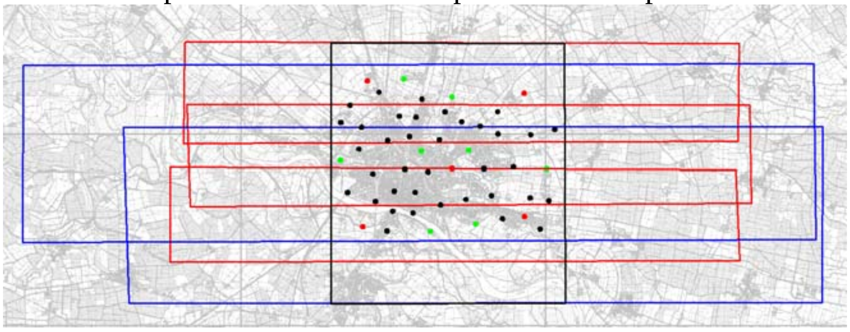


Figure 1. Structures of the 2000 m (red) and 4000 m (blue) blocks and the distributions of GCPs

2. METHODOLOGY

2.1 ETH Zurich Approach

Three different trajectory models have been developed and implemented by Gruen and Zhang (2003) for the triangulation of the TLS sensors. Two of them, the DGR and the LIM, are tested in this study. The DGR models the systematic errors of the image trajectory as a whole. 3 positional shifts, 3 attitude shifts and 3 attitude drift parameters are employed in the model. With the LIM, the EOP are determined in the so-called orientation fixes, which are introduced at certain time intervals. Between the orientation fixes, the EOP of an arbitrary scan line are interpolated using Lagrange polynomials.

The physical structure of the TLS camera is considered in the self-calibration model. A total of 18 APs have been identified, implemented, and tested at the IGP, ETH Zurich (Kocaman et al.

2006). The AP set consists of lens-based and CCD line based parameters. The self-calibration algorithm aims to determine the optimal set of APs for the optimal estimation of the object space coordinates of the image points. The adjustment procedure starts with the full parameter set and eliminates undeterminable parameters automatically in an iterative approach. A stepwise parameter elimination algorithm proposed by Gruen (1985) is used for this purpose.

2.2 The University of Pavia Approach

The Pavia group used the commercial software, Socet Set 4.4.1, Gpro 2.1 and Orima 6.1, supplied by the camera vendor. The trajectory model implemented in the Socet Set and Orima is based on the orientation fixes. In the bundle adjustment, the EOP of predefined orientation fixes are estimated. The EOP at any time are obtained through the linear interpolation of corrections.

Two different camera models are used for the tests. The first model, called here as **basic**, uses the given camera calibration data for pixel-to-image space transformation. An in-flight camera calibration is performed by the manufacturer and resulted in a look-up table, which includes the image coordinates of every CCD pixel. The lens distortion, offset and inclination of sensor lines are quantified in these values.

With the Orima software, it is possible to estimate a 7-parameter datum transformation in the case that GPS/IMU and GCP data relate to different reference systems. The misalignments between camera and IMU reference systems can also be treated as unknowns. In addition, a self-calibration method, which aims to improve the given calibration, can be performed. The Brown (1976) model, originally developed for frame cameras, has been implemented in Orima with 21 APs. The second camera model used for the tests, named here as **self**, includes self-calibration and datum transformation parameters. For more details on the camera models, please see Casella et al. (2007) and Kocaman et al. (2007).

3. RESULTS

The triangulations and the accuracy assessments have been carried out independently by the two groups. The stochastical model and the test network configurations were arranged identically. The sensor- and trajectory models are tested both with and without self-calibration. Two different GCP configurations (5 and 12 GCPs) are used.

The image coordinate measurements of the control points were manually performed at the University of Pavia and provided to the ETH Zurich group. 46 and 50 signalized control points were measured on the images of 2000 m flight and 4000 m flight, respectively. Tie points were extracted and measured automatically with the APM of Socet Set.

3.1 Direct Georeferencing Results

Direct georeferencing is performed by both groups using two different methods. The Pavia Group applied an aerial triangulation with very high constraints on the given trajectory values. The ETH Zurich Group used multiple weighted forward intersection. The results are quite similar in terms of object space residuals. Table 1 shows the results of the ETH Zurich Group. Both datasets show systematic error behaviour, as can be seen from the mean of the residuals.

	2000 m block			**4000 m block**		
Component	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)
RMSE	0.12	0.10	0.65	0.32	0.57	1.79
Mean	0.01	-0.01	-0.57	-0.14	0.34	-1.78
Sigma	0.10	0.10	0.22	0.15	0.18	0.39

Table 1. ETH Zurich results of direct georeferencing.

The sigma variable in Table 1 is computed via error propogation from the covariance matrix of spatial intersection according to:

$$\hat{\sigma}_X = \sqrt{\frac{\sum \hat{\sigma}^2_{X_i}}{n_X}} \qquad \hat{\sigma}_Y = \sqrt{\frac{\sum \hat{\sigma}^2_{Y_i}}{n_Y}} \qquad \hat{\sigma}_Z = \sqrt{\frac{\sum \hat{\sigma}^2_{Z_i}}{n_Z}} \qquad (1)$$

with n_X $n_{Y,}$ n_Z number of point coordinates used for the computation.

3.2 Triangulation Results of the 2000 m Flight

The triangulation results of the 2000 m flight dataset have already been presented in Casella et al. (2007) and Kocaman et al. (2007). The results of both groups are very similar when the self-calibration is performed.

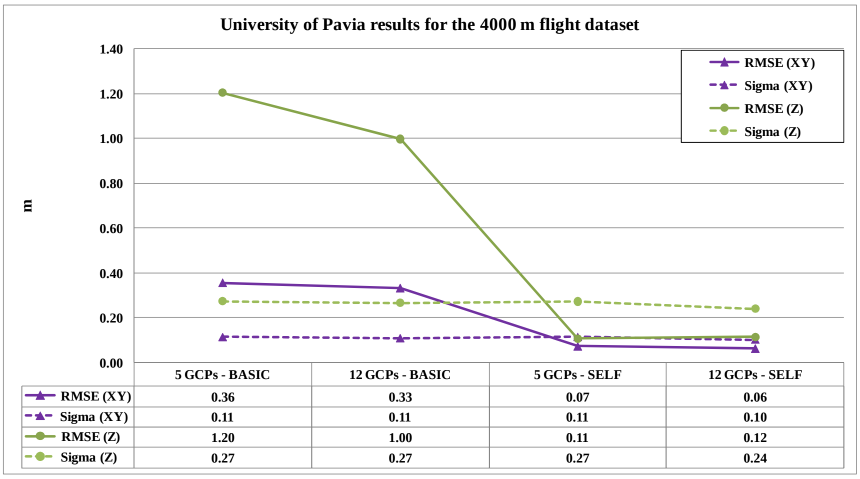
The Pavia results of the 2000 m tests produce the aposteriori sigma naught (sigma0) values between 0.35 and 0.43 pixels. When self-calibration is not performed, the RMSE values are around 1 pixel for planimetry and 1.4-2 pixels for height. The use of 12 GCPs instead of 5 improves the RMSE especially in height. Self-calibration greatly enhances the RMSE results, which are 5 cm (1/4 pixel) for planimetry and 9 and 6 centimeters (1/2 and 1/3 pixels) for height, when 5 and 12 GCPs are used, respectively. The large improvement with self-calibration highlights the existence of significant systematic errors in the system.

The DGR and the LIM models were tested at ETH Zurich with the same GCP configurations (5 and 12), both with and without self-calibration. The LIM was tested with 4 and 18 orientation fixes. The fix number 18 was chosen for an approximate match to the interval of the Orima orientation fixes. The fix number 4 was chosen to observe the effect of a smaller number of orientation fixes. The aposteriori sigma0 values of all tests ranged between 0.38-0.48 pixels. The test results without self-calibration showed large systematic errors, which were corrected by self-calibration. The RMSE values for both models without self-calibration were between 1.0-1.3 pixels for planimetry, and 0.4-1.0 pixels for height. With self-calibration, the RMSE values were in the range of 0.20-0.50 pixels for planimetry and 0.25-0.60 pixels for height. The best results were obtained with the DGR model and self-calibration. When the DGR was compared with the LIM-18, the DGR produced more stable results. This implies that the given trajectory values are accurate and even a less complex model is sufficient for modelling the trajectory errors. The 12 GCP cases resulted in better RMSE values in comparison to the 5 GCP cases.

3.3 Triangulation Results of the 4000 m Flight

3.3.1 University of Pavia Results

The Pavia results of the 4000 m tests are presented in Figure 2. When self-calibration is not performed, the RMSE values are between 0.85-0.92 pixel for planimetry and 2.5-3.0 pixels for the height. The use of 12 GCPs instead of 5 improves the RMSE especially in height. The self-calibration greatly enhances the RMSE results, which are then around 0.16 pixels for planimetry and 0.3 pixels for height. The large improvement with self-calibration again highlights the existence of significant systematic errors in the system.



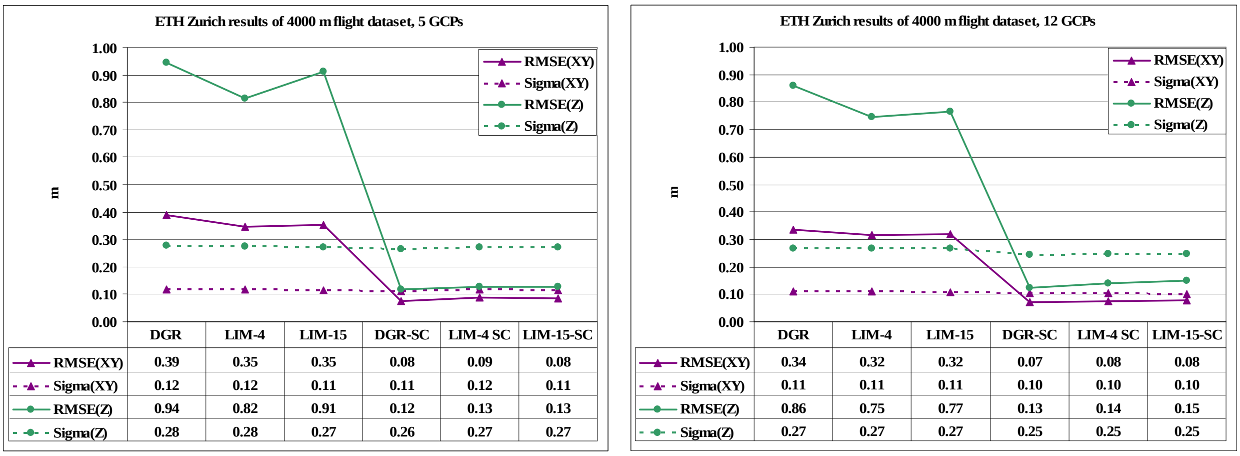
	5 GCPs - BASIC	12 GCPs - BASIC	5 GCPs - SELF	12 GCPs - SELF
RMSE (XY)	0.36	0.33	0.07	0.06
Sigma (XY)	0.11	0.11	0.11	0.10
RMSE (Z)	1.20	1.00	0.11	0.12
Sigma (Z)	0.27	0.27	0.27	0.24

Figure 2. Accuracy figures for the University of Pavia results

3.3.2 ETH Zurich Results

The DGR and the LIM are tested at ETH Zurich with the same GCP configurations (5 and 12), both with and without self-calibration. The LIM is tested with 4 and 15 orientation fixes. The fix number 15 is chosen for an approximate match to the interval of the Orima orientation fixes for this dataset. The fix number 4 is chosen to observe the effect of a smaller number of orientation fixes. The aposteriori sigma0 values of all tests range between 0.44-0.52 pixels. A graphical representation of the results of the 5 and 12 GCP cases are provided in Figure 3. The test results without self-calibration show large systematic errors, which are corrected by self-calibration.

The RMSE values obtained from the tests without self-calibration are between 0.8-1.0 pixels for planimetry, and 1.9-2.4 pixels for height. The LIM performs better than the DGR in height. Also, the use of 12 GCPs improves the RMSE height values slightly. The self-calibration improves the RMSE results. They are now in the range of 0.18-0.24 pixels for planimetry and 0.31-0.38 pixels for height. The DGR and the LIM results with self-calibration are very similar in planimetry, while in height the DGR is slightly better. The results of the 5 and 12 GCP cases are very similar in all self-calibration tests.



	DGR	LIM-4	LIM-15	DGR-SC	LIM-4 SC	LIM-15-SC
RMSE(XY)	0.39	0.35	0.35	0.08	0.09	0.08
Sigma(XY)	0.12	0.12	0.11	0.11	0.12	0.11
RMSE(Z)	0.94	0.82	0.91	0.12	0.13	0.13
Sigma(Z)	0.28	0.28	0.27	0.26	0.27	0.27

	DGR	LIM-4	LIM-15	DGR-SC	LIM-4 SC	LIM-15-SC
RMSE(XY)	0.34	0.32	0.32	0.07	0.08	0.08
Sigma(XY)	0.11	0.11	0.11	0.10	0.10	0.10
RMSE(Z)	0.86	0.75	0.77	0.13	0.14	0.15
Sigma(Z)	0.27	0.27	0.27	0.25	0.25	0.25

Figure 3. ETH Zurich results of the triangulation of 4000 m flight dataset with 5 GCPs (left) and 12 GCPs (right)

4. CONCLUSIONS

Two ADS40 image blocks acquired over the Pavia test site are processed in terms of triangulation and self-calibration by the University of Pavia and ETH Zurich. Different trajectory models and self-calibration methods are used by both groups.

The direct georeferencing results of both groups are identical in terms of RMSE. The 2000 m dataset provides a good level of accuracy, 0.5 pixels in planimetry and 3 pixels in height, even without the use of GCPs. The direct georeferencing results of the 4000 m block are worse with 1.2 pixels in planimetry and 4.6 pixels in height.

The University of Pavia approach uses the commercial software Orima of Leica Geosystems for the triangulation and self-calibration. For the 2000 m block, the best results are obtained with the 12 GCP configuration and by using self-calibration. In this case, the RMSE values are equal to 5 cm and 6 cm (0.25 and 0.30 pixels) in planimetry and in height, respectively. For the 4000 m block, the best results are obtained again by using self-calibration. In the 5 GCP case, the RMSE values are 7 cm and 11 cm (0.18 and 0.29 pixels) in planimetry and in height, respectively. The use of 12 GCPs does not lead to any improvement in this case.

The ETH Zurich results are comparable to Pavia results when the self-calibration is used. For the 2000 m block, the best results are obtained using the DGR model with self-calibration and 12 GCPs. In this case, the RMSE values are 4 cm and 5 cm (0.2 and 0.25 pixels) in planimetry and height, respectively. For the 4000 m block, using the DGR with 5 GCPs and with self-calibration, the RMSE values result in 8 cm and 12 cm (0.2 and 0.3 pixels) in planimetry and height, respectively. The use of self-calibration improves the accuracy in all cases.

Overall, the self-calibration brings a great improvement to the triangulation accuracy. This improvement is even more significant with the 4000 m block, which has probably less accurate given trajectory values. The results of both groups are very similar when self-calibration is applied.

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