APPLICATION AND ACCURACY EVALUATION OF LEICA ADS40 FOR LARGE SCALE MAPPING

WenYuan Hu[a], GengYin Yang[b], Hui Yuan[c,*]

[a, b] ShanXi Provincial Survey and Mapping Bureau, China - sxgcchy@public.ty.sx.cn
[c] ERDAS Inc., China – hui.yuan@erdas.com

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ABSTRACT:

Leica ADS40 photogrammetry system is one of the advanced aerial survey and mapping systems. Based on the three linear CCD arrays and pushbroom technology, ADS40 enables the quick acquisition of high spatial resolution, panchromatic, and multispectral images as well as stereo models with various viewing angles. Due to the linear scanning nature, each ADS40 image consists of a large number of scanned lines. The operational ADS40 system aboard consists of not only the optical scanner but also the Global Positioning System (GPS) and Inertial Measurement Unit (IMU). During the acquisition flight, the GPS/IMU system records the absolute and relative positions and attitudes of the aircraft in a continuous manner, which makes the direct referencing possible right after the flights. The processing workflows of ADS40 images are different from the processes of the traditional frame camera images in many ways. Up to date only a few commercially available software packages can process ADS40 data sets. Although the ADS40 has been widely used by various mapping agencies worldwide, the ADS40 images were firstly taken by the China photogrammetry market in 2006. Due to absence of such an ADS40 application example in China, this paper is to present a pilot ADS40 project for large scale mapping productions. These studies were performed by the ShanXi Provincial Survey and Mapping Bureau, China and supported by the Leica Geosystem of China. In this paper we describe the general ADS40 processing workflow using the Leica Photogrammetry Suite System, which have been proven to be effective from the empirical study. In our study, we present the experimental studies using three data sets with various scales. The accuracy achieved with these three ADS40 data sets meets or exceeds the required accuracy not only based on its triangulated results but also on the stereo analysis on large number of independent check points. In reference to the experimental results, the factors which might affect the mapping accuracy are analyzed. First of all, the local coordinate system has to be defined properly and the coordinate conversion accuracy and its influence is presented and analyzed. The effects of GCPs and the optimal number of GCPs are also discussed. It is concluded from this study that the bundle adjustments using four GCPs is optimal. Through the tremendous efforts of processing three sets of ADS40 data, we find that that the quality of the tie points generated from the automated point matching (APM) is critical to the success of the ADS40 process. In a summary, we conclude from the empirical study that the ADS40 is one of the ideal aerial data sets for large scale mapping applications and the resulting accuracy is superior to the corresponding mapping standard sets from the traditional frame camera images.

1. INTRODUCTION

The Leica ADS40 photogrammetry system is one of the advanced digital aerial survey and mapping systems, which is characterized with its three linear CCD arrays and pushbroom technology. Based on the advanced Tetrachroid technology, the latest ADS40 with a single lens and a total of 11 CCD lines with 12,000 pixels each can acquire a large swath of high spatial resolution Panchromatic and multi-spectral imagery at various viewing angles from each single flight. The operational ADS40 system is equipped with the optical scanner, the Global Positioning System (GPS), and Inertial Measurement Unit (IMU). The GPS/IMU system records the absolute and relative positions and attitudes of the aircraft during the acquisition flight. The recorded position and attitude information is the key part of a direct geo-referenced ADS40 system and must be processed and integrated properly to calculate the exterior orientation of each image line after flight data sets are downloaded for each flight project (Tempelmann, U. et. al. 2000). These particular advantages lead to wide acceptance of ADS40 in the photogrammetry market worldwide. Currently more than fifty ADS40 cameras are in use by various mapping agencies around the world. However, the application of ADS40 in China did not start until 2006.

* Corresponding author

In this paper we present a pilot study of ADS40 for various mapping scales conducted by the ShanXi Provincial Survey and Mapping Bureau, China. In the section two, the test projects and general ADS40 workflow are described. The definition of the local mapping coordinate system is introduced. The experimental results and accuracy evaluation are summarized in the section three. In the section four, based on the findings of the project, recommendations and conclusions are made as to the applicability of ADS40 in various mapping scales in China.

2. TEST STUDIES AND ADS40 WORKFLOW

2.1 Test Studies

The ShanXi province located in the middle North of China covers 15.6 Square Kilometers. Historically the topographic maps at 1:10,000 scale in the ShanXi province were mainly produced during 1990s and could not show the true ground condition with the fast pace of urbanization. Updating topographic maps at higher mapping scales is more challenging in terms of the project cost and timing because most of the traditional photogrammetric workflows have to deal with hundreds of frame images in one project and require a number of Ground Control Points (GCPs) from laborious field works and thus can not be fulfilled by an automated process. As a comparison, the ADS40 workflow is mainly automated. Thanks to the direct geo-referenced scheme, only a few of GCPs are needed for rigorous bundle adjustment. This significantly reduces the time to produce large swath of orthorectified maps and can provide most accurate geospatial data products for many GIS and remote sensing applications at different levels of spatial and spectral resolutions.

Since the application of ADS40 in China is very new at the time of the project, this study is to show and verify the accuracy and suitability of ADS40 data sets for various large mapping projects from 1:10,000, 1:5000, 1:2,000, to 1:500. Three flight projects were completed in the three cities of Tai Yuan, Ping Yao, Tai Gu in the ShanXi province. The ADS40 data sets were collected at three kinds of ground sampling distances (GSD): 0.5 meter, 0.2 meter, and 0.06 meter. The detailed project information is shown in Table 1.

Study Area	Acquisition Time	GSD (m)	Area (km^2)	Mapping Scales
Tai Yuan	11/11/2006	0.5	1560	1:10,000 1:5,000
Ping Yao	10/22/2006	0.2	240	1:2,000
Tai Gu	05/19/2007	0.06	30	1:500

Table 1. Project Information

2.2 ADS40 workflow and software

A typical ADS40 workflow is described in Figure 1. The overall process includes data download, GPS/IMU processing and integration, L0 and L1 image rectification, bundle adjustment, quality assurance, and specified data extraction tasks. In this project, all the processes are implemented using Leica Photogrammetry Suite including GPRO, IPAS, ORIMA, and LPS.

In this paper we focus on the accuracy assessment of ADS40 data sets by well-distributed true ground check points. The general steps for each study area in this project are summarized as below:

1. Data download
2. GPS/IMU processing and Integration
3. L0 non-rectified image generation
4. Run L0 Automated Point Measurements (APM)
5. Block bundle adjustments using densely distributed tie points and four ground control points in ORIMA
6. L1 triangulated image generation
7. Create a new LPS project file using the local Cartesian coordinate system and load the L1 images
8. Stereoscopic measurement by skillful operators
9. Accuracy assessment

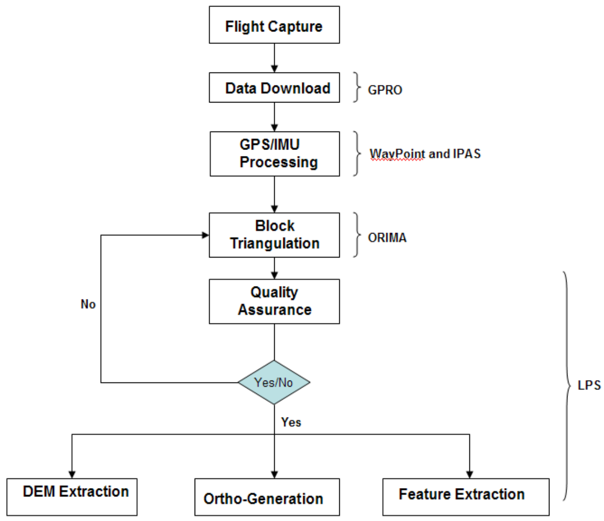

Figure 1. ADS40 Processing Workflow

2.3 Local Coordinate Conversion

Because of the use of GPS/IMU, the resulting reference system of the ADS40 is built on the World Geodetic System (WGS84). Thus there is one inevitable concern when the ADS40 is used in China, i.e., the coordinate conversion. In China, the commonly used reference system for national and local mapping is based on the ellipsoid National 1980 Xi'An ellipsoid and the vertical system is the National 1985 Geoid datum. Thus how the conversion between the World Geodetic System and the China reference system to be implemented has become a first challenge we have to tackle in this project.

To ensure most accurate conversion, the transformation between WGS84 and the local China coordinate system is divided into two parts: horizontal and vertical. The horizontal conversion is implemented by 7 ellipsoidal parameters and the vertical datum is defined based on the regularly spaced vertical shifts between the WGS84 ellipsoid and local Geoid height.

Using three high fidelity ground control points, the 7 parameters between WGS84 and Xi'An 80 are calculated including the x, y, and z transitions to WGS84 in meters, the omega, phi, kappa rotations to WGS84 in radians, and the scale change to WGS84 in scientific notation. The seven parameters are then defined in the ASCII file called spheroid.tab in the ERDAS IMAGINE/LPS system in a format as below:

```
"Spheroid Name" {
 Sequence_Number Semi-Major_Axis Semi-Minor_Axis
 "Datum Name 1" dx dy dz rw rj rk ds
 "Datum Name 2" dx dy dz rw rj rk ds
..........
}
```

To ensure the best conversion accuracy, the 7 parameters are calculated respectively for each study area, and defined as individual horizontal datum under the Xi'An ellipsoid. The horizontal conversion accuracy is strictly verified by a number of indepedently chosen check points. These check points have been surveyed with both coordinate systems of the WGS84 and the local coordinate systems. The results from the horizontal accuracy verification are shown in Table 2. From the Table 2, we can observe that the conversion accuracy is within 0.01 m in all study areas.

Study Area	Number of Check Points	RMSE of X (m)	RMSE of Y (m)
Tai Yuan	22	±0.004	±0.004
Ping Yao	15	±0.004	±0.001
Tai Gu	21	±0.010	±0.008

Table 2. Horizontal Local Coordinate Conversion Accuracy

The vertical shifts from the local vertical datum to the WGS84 ellipsoid height is converted into a GRID binary file and a reference to the binary grid file is added into spheroid.tab as a surface datum. The vertical shifts are provided by an authoritative source and its vertical accuracy is assured in 0.05 meter.

After the local horizontal and vertical system is properly defined, the conversion between the WGS84 system and the China mapping system is automatically performed in GPRO, ORIMA, and LPS. Based on the verified accuracy, the conversion process shall meet the mapping accuracy for all the targeted mapping scales and thus its adverse influence on the final mapping accuracy is negligible.

3. ACCURACY EVALUATION

3.1 Block Bundle Adjustment Results

For each of the three study areas, densely distributed tie points were generated in GPRO before block bundle adjustments in ORIMA. Based on the orientation fix point methodology (Hinsken et al., 2002), the ORIMA adjusted the exterior orientation of the orientation fixes by densely distributed tie points and a few of ground control points. The inaccuracy from the direct orientation of the GPS/IMU or datum conversion is compensated by the bundle adjustment process. Then the adjusted orientation fixes are interpolated to adjust the orientation of each scanning line.

Due to the rigid geometric nature of ADS40, densely distributed tie points within and between flight strips are needed for orientation adjustments and greatly reduces the need of GCPs. From tremendous efforts of bundle adjustments, we found that the quality of tie points in terms of its accurate location and distribution has become a key to the success of the bundle adjustment. How to generate high quality tie points are not in the scope of this paper due to the limit of paper space but certainly need to be paid special attention when dealing with ADS40 projects.

Instead, in this paper we will show how various numbers of GCPs influence the bundle adjustment results. We experimented with the bundle adjustments using different number of control points. For the study area Tai Yuan and Ping Yao, three bundle adjustments were performed using zero, four, nine GCPs while two bundle adjustments were run for the Tai Gu study area. This is because we found it is impractical to obtain the satisfactory accuracy for the large mapping scale 1:500 from a bundle adjustment without GCP.

Each of the bundle adjustments were performed in ORIMA. The resulting accuracy is summarized for each study area using different number of GCPs. The accuracy reports for the Tai Yuan, Ping Yao, and Tai Gu are shown in Table 3, 4, ad 5. According to the tables, in all the study cases, the RMSE of the GCPs are within one GSD size. The small RMSE of the antenna centers and IMU angles indicates stable adjustments on the original GPS/IMU orientation. Generally to say, the bundle adjustments using four GCPs performed well than others based on the ORIMA accuracy reports.

No. of GCPs	RMSE of GCPs (m)			RMSE of Antenna Centers(m)			RMSE of IMU Angles (Degree)		
	X	Y	Z	X	Y	Z	X	Y	Z
0				0.022	0.018	0.068	0.004	0.004	0.016
4	0.23	0.19	0.09	0.015	0.014	0.025	0.004	0.003	0.016
9	0.33	0.20	0.12	0.015	0.014	0.025	0.004	0.003	0.016

Table 3. ORIMA Accuracy Report for the Tai Yuan (0.5 m GSD)

No. of GCPs	RMSE of GCPs (m)			RMSE of Antenna Centers(m)			RMSE of IMU Angles (Degree)		
	X	Y	Z	X	Y	Z	X	Y	Z
0				0.023	0.026	0.014	0.004	0.0027	0.015
4	0.026	0.045	0.026	0.023	0.027	0.015	0.004	0.0026	0.015
9	0.076	0.108	0.057	0.023	0.026	0.014	0.004	0.0027	0.015

Table 4. ORIMA Accuracy Report for the Ping Yao (0.2 GSD)

No. of GCPs	RMSE of GCPs (m)			RMSE of Antenna Centers(m)			RMSE of IMU Angles (Degree)		
	X	Y	Z	X	Y	Z	X	Y	Z
4	0.044	0.046	0.022	0.011	0.017	0.015	0.005	0.003	0.009
9	0.043	0.039	0.033	0.011	0.017	0.015	0.005	0.003	0.009

Table 5. ORIMA Accuracy Report for the Tai Gu (0.06 m GSD)

3.2 Quality Assurance and Discussions

Although the bundle adjustments have shown good performance, we are not sure whether it is the true representation of the final mapping accuracy. It is our purpose to verify the feasibility of ADS40 for large scale mapping in China. To fulfill the accuracy assessment tasks, we collected a large number of well distributed ground check points to evaluate the mapping accuracy via the direct stereoscopic measurement by skillful operators. The distribution of these check points is well designed as shown in Figure 2 to Figure 4 to evenly cover the whole study area for each. These ground check points were surveyed and provided in the China mapping system, i.e., the Xi’An 80 horizontal system and 1985 vertical datum. Their quality and fidelity are confirmed by different quality control groups.

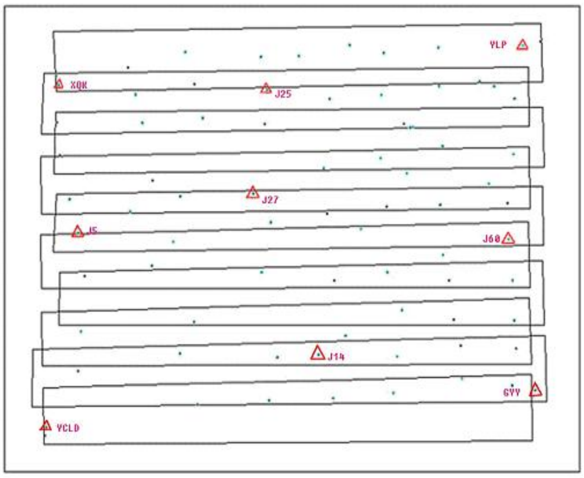

Figure 2. Distribution of Ground Points for Tai Yuan (0.5 m)

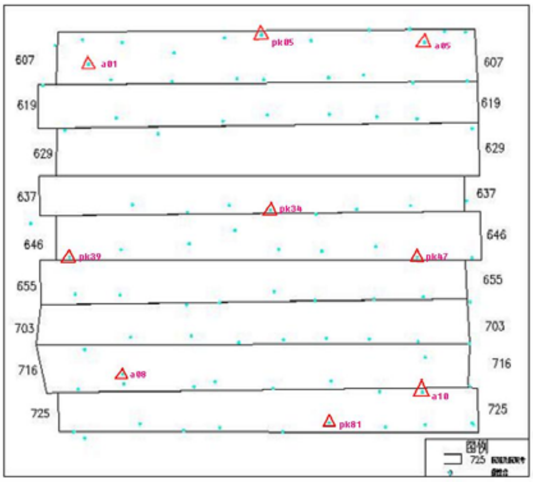

Figure 3. Distribution of Ground Points for Ping Yao (0.2 m)

For each ADS40 strip there are three stereo pairs available for stereo viewing. Among them, we decided to use the panchromatic stereo pairs of the Forward 28° and the Backward 14° to avoid any bias caused by different viewing angles. The ground coordinates for each check points based on the stereoscopic measurement were recorded and compared with the surveyed ground coordinates. The final accuracy comparison reports are shown from Table 6 to 8. From the tables, the RMSE is the root of mean squared error between the visually measured ground coordinates and the surveyed ground coordinates. The Maximum Residual is the maximal difference between the visually measured ground coordinates and the surveyed ground coordinates among all the check points.

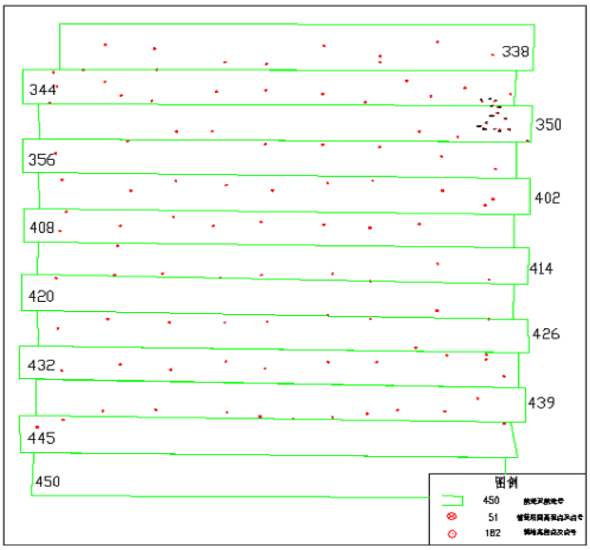

Figure 4. Distribution of Ground Points for Tai Gu (0.06 m)

No. of GCPs	No. of Check Points	RMSE（m）			Maximum Residual（m）		
		X	Y	Z	X	Y	Z
Zero	79	0.80	0.72	0.91	1.77	1.67	1.96
Four	75	0.27	0.34	0.40	0.76	0.88	0.88
Nine	70	0.29	0.32	0.35	0.83	0.88	0.87

Table 6. Check Point Accuracy Report for the Tai Yuan (0.5 m)

No. of GCPs	No. of Check Points	RMSE（m）			Maximum Residual（m）		
		X	Y	Z	X	Y	Z
Zero	88	0.26	0.23	0.18	0.60	0.54	0.40
Four	84	0.15	0.19	0.19	0.45	0.43	0.45
Nine	78	0.17	0.17	0.15	0.48	0.50	0.42

Table 7. Check Point Accuracy Report for the Ping Yao (0.2 m)

No. of GCPs	No. of Check Points	RMSE（m）			Maximum Residual（m）		
		X	Y	Z	X	Y	Z
Four	101	0.07	0.05	0.06	0.12	0.10	0.13
Nine	101	0.07	0.06	0.06	0.19	0.21	0.21

Table 8. Check Point Accuracy Report for the Tai Gu (0.06 m)

We observe from these three tables that there is no significant difference between horizontal (X and Y) and vertical Z accuracy. In some cases the vertical Z accuracy is even better than that of the horizontal X and Y. According to the National Mapping specifications for 1:10,000, 1:5000, 1:2000, and 1:500 (GB

13990-1992 and GB 7930-1987), the obtained vertical accuracy is better than the required vertical accuracy. We anticipate this is because the stereo pairs with 42° viewing angles has large base to height ratio close to 0.8 and improves the vertical accuracy (Cramer, M., 2006).

By a general study, the accuracy from the 0.5 m Tai Yuan meets all the accuracy requirements for both 1:10,000 and 1:5000 mapping scales. The acquired 0.5 m ADS40 data sets can meet the required accuracy for the 1:10,000 mapping scale even when no GCP is used. However, for 1:5,000 mapping, it is necessary to have GCPs to meet the required accuracy. Four GCPs are recommended. From our analysis, it shall be sufficient to obtain satisfactory accuracy horizontally and vertically.

For the 0.2 m Ping Yao study area, we see similar results as the 0.5 m Tai Yuan study area. The accuracy from the case using zero GCP is acceptable. However, the best result is obtained from the case using four GCPs. For the 0.06 m Tai Gu study area, there is no significant difference observed for the two cases using four and nine GCPs.

Tables 6 to Table 8 showed the maximum residual among the check points for each of the study case. By studying the locations of the check points with large residuals, it was found that the check points distributed on the boundary of the study areas are relatively poorer than those in the middle part, indicating relatively weaker geometric condition on the edge area.

4. CONCLUSION

In this empirical study, we used three sets of ADS40 data sets in different GSD sizes to test the overall ADS40 workflow and assessed the accuracy and applicability of the ADS40 data sets to various mapping scales in the China reference system.

From the empirical study, several key points are summarized. First of all, the quality and distribution of tie points is the key to the success of the ADS40 bundle adjustments. Generally to say, if the matched tie points are good enough within four pixels and also shows good tie connection between strips, four GCPs shall be sufficient for bundle adjustment to obtain satisfactory accuracy for all mapping scales. This undoubtedly reduces laborious field work collecting large number of GCPs especially in difficult areas and in the mean time greatly speeds up various production cycles of geospatial data without any sacrifice of spatial accuracy.

REFERENCES

Cramer, M., (2006). The ADS40 Vaihingen/Enz geometric performance test, ISPRS Journal of Photogrammetry & Remote Sensing 60 (2006) 363–374.

Tempelmann, U. et. al. (2000). Photogrammetric Software for the LH Systems ADS40 Airborne Digital Sensor) Int. Arch. of Photogrammetry and Remote Sensing. Vol. 33, Part B2, pp. 552-559, Amsterdam, Netherlands.

Hinsken, L., Miller, S., Tempelmann, U., Uebbing, R., Walker, S., 2002. Triangulation of LH Systems' ADS40 imagery using ORIMA GPS/IMU. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 34 (Part 3A),156–162.

GB 13990-1992, Specifications for aerophotogrammetric office operation 1:5000, 1:10000 topographic maps

GB 7930-1987, Specifications for aerophotogrammetric office operation 1:500, 1:1000, 1:2000 topographic maps