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First Experiences with *CCNS/AEROcontrol* in China

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Keywords: photogrammetry, aerial photography, Differential Global Position System (DGPS), Inertial Measurement Unit (IMU), Direct Georeferencing (DG), Integrated Sensor Orientation (ISO),

Summary: With the introduction of *CCNS/AEROcontrol* system in November 2002 the first DGPS/IMU-based photogrammetric project in China was successfully accomplished jointly by the Chinese Academy of Surveying & Mapping (CASM) and the Germany-based companies IGI and Techedge. Using the aerial camera *LKM 2000* and based on the *CCNS/AEROcontrol*, two photogrammetric blocks in Anyang, China, were flown with a photo scale of 1 : 4000 (for 1 : 1000 scale mapping) and 1 : 20000 (for 1 : 5000 scale mapping) respectively. The flight results were processed and evaluated directly after the aerial photography. After the film development and photo scanning a digital aerial triangulation was conducted for the calibration field using the China-made *GeoLord-AT* software. Based on the calibration data exterior orientation (EO) parameters of all images of the entire block were determined without using any ground control points (GCPs). Integrated sensor orientation was also conducted based on acquired DGPS/IMU data without any ground control or with a limited number of GCPs. The quality of EO parameters were proven by using many ground check points. The results are promising. The paper describes individual procedures of the project. Results are presented and evaluated. The paper concludes with further suggestions and outlook for the DGPS/IMU-based photogrammetric production in China.

Zusammenfassung: *Erste Erfahrungen mit CCNS/AEROcontrol in China.* Mit der Einführung des *CCNS/AEROcontrol* Systems im November 2002 wurde das erste DGPS/IMU-gestützte photogrammetrische Projekt in China durch eine Kooperation zwischen der Chinese Academy of Surveying and Mapping (CASM) und den deutschen Firmen IGI und Techedge erfolgreich abgeschlossen. Ausgerüstet mit der Luftbildmesskammer *LMK 2000* und unterstützt durch *CCNS/AEROcontrol* wurden zwei Blöcke jeweils für einen Bildmaßstab von 1 : 4000 (zur Kartenherstellung für 1 : 1000) und 1 : 20000 (zur Kartenherstellung für 1 : 5000) in Anyang, China, geflogen. Die Befliegungsdaten wurden direkt nach der Aufnahme verarbeitet und bewertet. Nach der Filmentwicklung und -digitalisierung wurde eine digitale Aerotriangulation über das Kalibrierungsfeld mit der chinesischen Software *GeoLord-AT* durchgeführt. Mit Hilfe der Kalibrierungsdaten wurden äußere Orientierungsparameter aller Bilder eines ganzen Blocks ohne Verwendung von Passpunkten ermittelt. Eine integrierte Sensororientierung, der die DGPS/IMU-Daten zugrunde liegen, wurde auch ohne bzw. mit Verwendung einer minimalen Anzahl von Passpunkten durchgeführt. Die Qualität der Orientierungsparameter wurde anhand von zahlreichen Geländepunkten überprüft. Die Ergebnisse sind vielversprechend. Der Beitrag beschreibt Einzelheiten über das Projekt, präsentiert und bewertet die erzielten Ergebnisse und endet mit weiteren Vorschlägen und einem Ausblick für die DGPS/IMU-gestützte photogrammetrische Produktion in China.

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1 Introduction

With its opened door to the world People's Republic of China has become one of the focuses of the world economy since last two decades. Notwithstanding the current world-wide economic crisis, China's economy is booming year by year. New policies adapted for international standards since the China's entry into the World Trade Organization (WTO) attract and motivate more and more investors to China, where an even higher stage of development is to be expected in the coming future.

To bring the prosperity to a new stage the Chinese government has launched the most challenging program "Go West", aiming at developing the backward western regions, and thus, narrowing the gap of wealth to the coastal area in the east. West China is a vast, beautiful, fertile and mysterious land. It covers more than half of China's land mass and is home to 285 million people. There is full of potential for development.

The rapid development in China today demands for a higher actuality of spatial information over the whole country than ever before and raises a great challenge to the surveying and mapping community in China. There is still one-fifth of the territory (mainly in West China) without maps of 1 : 50000 scale, and one-third of the available maps were produced based on aerial photographs taken in the seventies and the eighties of the last century. Therefore, to speed up the map production stands in the foreground of surveying and mapping in China.

With the latest development in techniques and technologies digital processing has already replaced analytical plotting in the photogrammetric production of China. Each provincial Bureau of Surveying and Mapping is well equipped with a large number of China-made digital photogrammetric workstations (*DPWS*). Once digital or digitized images are available, the automated photogrammetric production is carried out. Automation of major photogrammetric procedures replaces the most time-consuming labor work by computers, and thus, speeds up the entire production considerably. However, there are still some major obstacles to the efficiency and intensive human work is still required, e.g. photographs have to be digitized, cartographic features should be extracted, and ground control points (GCPs) must be collected and measured in the field. Image digitization can be accelerated considerably by adding some automatic mechanisms on the film scanner, or ignored completely when digital aerial cameras are applied. Feature extraction can profit a lot from *DPWS* automated functions being improved gradually with the current technical progress. Now, the task of GCP collection and measurement remains the inevitable labor work, which slows down the production directly on the one hand, and makes mapping of e.g. desert and inaccessible regions in west China very hard or even impossible on the other.

Thus, aerial photogrammetry without any ground control or with a limited number of GCPs is the prerequisite for speeding up the map production so as to meet the demands of rapid development in China and closing the map gap in the country's western regions, in particular.

2 Project "Anyang"

Direct georeferencing (DG) based on differential global positioning system (DGPS) and inertial measurement unit (IMU) technologies opens a new era of aerial photogrammetry without or with little ground control (e. g. Cramer 2002). Latest successful applications of this kind of technology in Europe and the North America reported (e. g. Kremer 2002) encouraged the Chinese Academy of Surveying and Mapping (CASM) in Beijing, the key institution for research and engineering of the State Bureau of Surveying and Mapping (SBSM) of China, to prove and explore the applicability and the potential of this technology for mapping in China by its own.

With the successful import of a *CCNS/AEROcontrol* system (Grimm 2003) in November 2002 CASM started the first DGPS/IMU-based photogrammetric project in China in cooperation with the Germany-ba-

Tab. 1: Anyang *CCNS/AEROcontrol* mission parameters.

	Mission A	Mission B
Photo scale	1:4000	1:20000
Map scale	1:1000	1 : 5000
Terrain type	flat	flat/hilly
Area	5 km × 2.5 km	14 km × 22 km
Block size	5 strips × 18 photos	7 strips × 16 photos
Calibration field	Inside the block, one more strip of 11 photos	outside the block, two strips of 11 photos each
Flight date	18/11/02 19/11/02	03/01/03
Aerial camera	Carl Zeiss Jena *LMK 2015*	
Airplane	*Yun-5* (made in China)	

sed companies IGI and Techedge. Anyang, a city of Henan Province, about 500 km south of Beijing, was chosen for the test flights. Two missions of aerial photography were planned and conducted for a photo scale of 1:4000 (for 1:1000 scale mapping) and 1:20000 (for 1:5000 scale mapping) respectively. Tab. 1 shows the mission parameters.

3 Goal and Objectives

Goal of the Anyang project is to prove the applicability of *CCNS/AEROcontrol* system for topographic mapping in China and gain the first experiences thereof for all participating parties.

Major objectives of the project are:

- Installation and operation of *CCNS/AERO control* system,
- Training with *WinMP*, *GrafNav* and *AERO office* software,
- Training with GPS base station,
- Establishing a calibration field and conducting GPS measurements,
- Getting started with a typical *CCNS/AERO control* project to test and prove its applicability for mapping of the proposed scales,
- Performing the *CCNS/AEROcontrol*-based test flights,
- Conducting the system calibration (boresight alignment),
- Conducting GPS/IMU data post-processing,
- Conducting aerial triangulation (AT) and integrated sensor orientation (ISO),
- Comparing the GPS/IMU results with AT and ISO ones,
- Gaining the first experiences in China with:
  - How to run a *CCNS/AEROcontrol*-based project,
  - How to establish the calibration field to best fit for any kinds of applications,
  - What effects could be expected using system calibration based on different image scales,
  - How much the positioning accuracy could be influenced by the location of a GPS base station,
  - How well the GPS/IMU-based direct geo-referencing can meet the requirements for map production,
  - How much ground control points (GCPs) could be saved for the case of ISO,
  - How much time and costs could be saved for productions using GPS/IMU technologies.

4 Workflow and Procedures

Fig. 1 shows the workflow designed and actually followed for the Anyang project. Three major work phases were involved, i.e. preparation, mission and data processing. In the following, individual procedures are briefly described.

4.1 *Preparation*

In contrary to conventional aerial photography some additional preparation work should be done before a *CCNS/AEROcontrol* mission can be started.

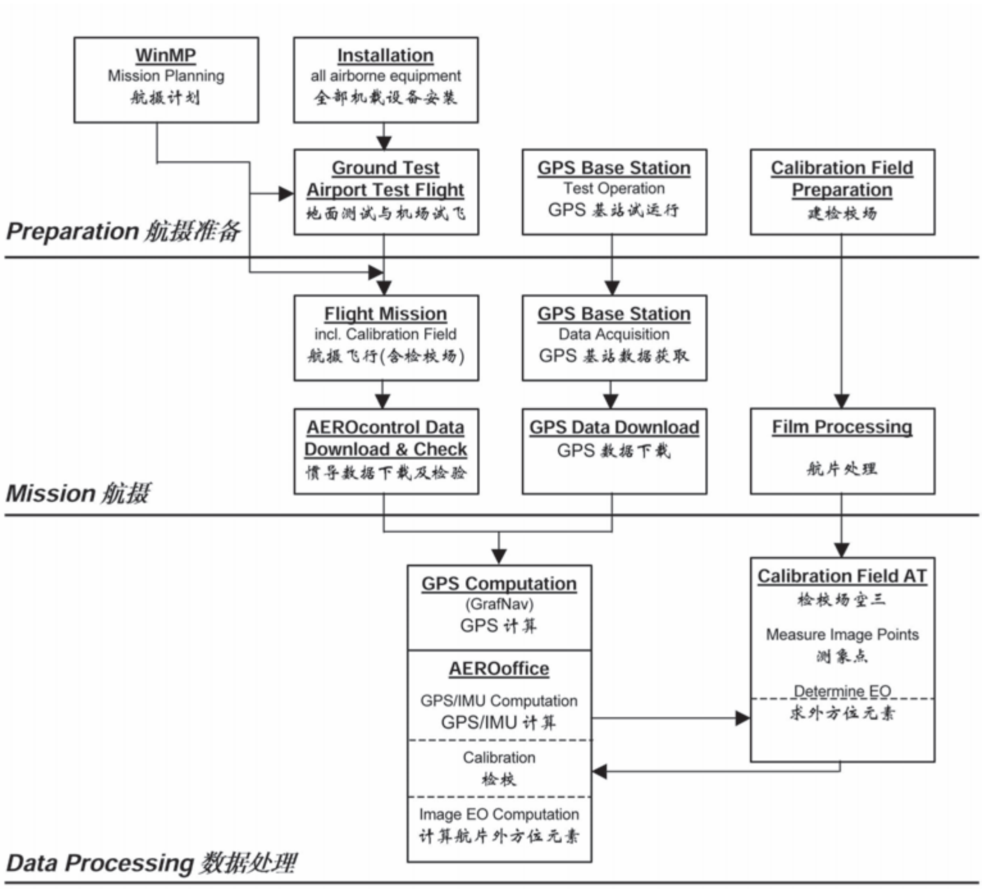

Fig. 1: Workflow of a DGPS/IMU-based photogrammetric project.

System installation and tests

In addition to aerial camera *CCNS* and *AEROcontrol* computers as well as GPS receiver have to be fixed in the aircraft. Using a camera-specific mount ring the IMU can be mounted on the aerial camera. GPS antenna should be mounted on top of the aircraft with its plummet as close to the center of camera objective as possible. Lever-arms have be measured for late data processing. After system installation a ground test has to be conducted to check if all airborne system components work properly. If possible, an airport test flight is highly recommended e.g. before conducting a large area mission.

Mission planning

Using the *WinMP* software missions can be planned in a very comfortable way. Fig. 2 shows the *WinMP* results for the Anyang missions.

Calibration field preparation

For the so-called boresight alignment a calibration field should be established. A block of two strips of 11 photos each with a side overlap of 60 % is recommended by IGI. It can be located inside or outside the mission area. Fig. 2 also shows the calibration fields designed for the Anyang missions. Six or more GCPs well distributed over the block should be measured. Signalized GCPs are

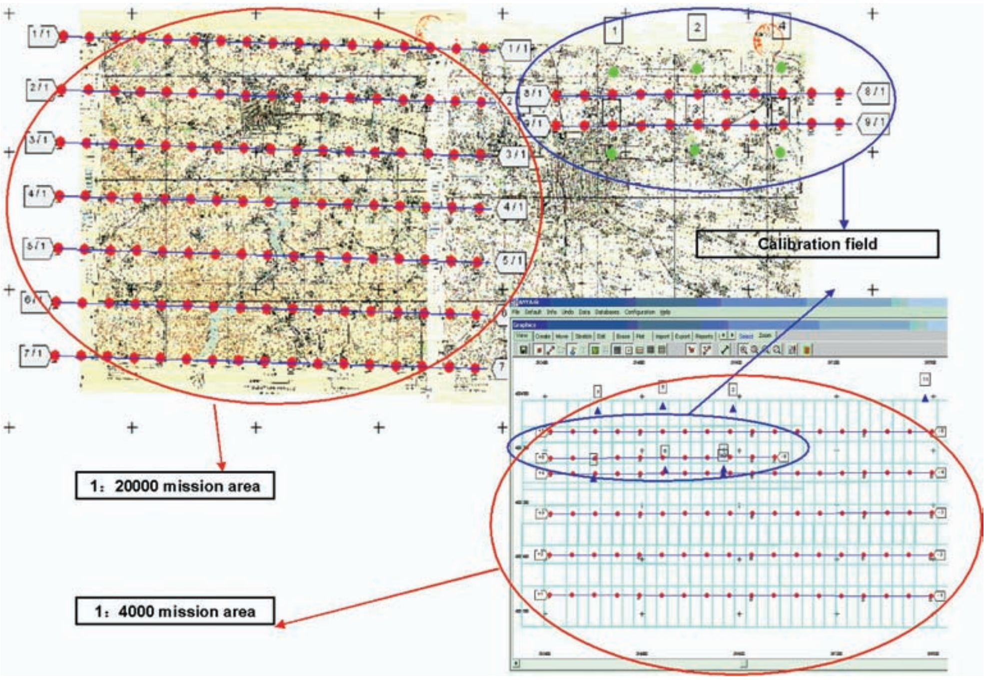

Fig. 2: Mission planning and calibration field.

desirable. However, since we wanted to gain experiences for the real photogrammetric practice in China, nature points (but one) were used only this time. Note: A calibration field is essential for DG only. An integrated sensor orientation (ISO) can completely save this additional work.

GPS base station

For DGPS measurements one GPS base or reference station is a prerequisite. Ideally it should be located within a circle of a radius of 30 km to the mission area. Concerning many special cases in China (e. g. inaccessible regions) effects of GPS base station location became one of the major objectives of the Anyang project. Thus, several GPS base stations of different distances to Anyang were simultaneously used for the missions (Fig. 3).

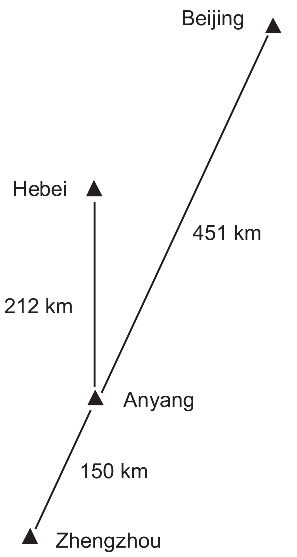

Fig. 3: Used GPS base stations.

4.2 *Mission*

After the preparation phase a mission can be conducted with the help of *CCNS* guidance based on *WinMP* planning. Data acquisition by *AEROcontrol* onboard and at GPS base station(s) have to be done simultaneously. After the flight all kinds of data acquired (e. g. GPS, IMU) are downloaded to the office computer and film is taken to the development. Fig. 4 shows the aircraft used for the Anyang project. GPS observation conditions for all Anyang missions can be found in Tab. 2. While the Anyang base station was used for the flight mission on November 18 (coded as A18) only, Beijing and Hebei base stations recorded data during the mission on November 19 (coded A 19) additionally. During the mission B on January 3, 2003, Beijing, Zhengzhou and Anyang base stations made data acquisition simultaneously.

Fig. 4: *Yun-5* survey aircraft.

4.3 *Data processing*

Based on GPS and IMU data acquired during the flight positions and attitudes of the aerial photos can be determined by means of Kalman filtering (e.g. Cramer 2002, Kremer 2002). An aerial triangulation (AT) for

Tab. 2: GPS observation conditions.

	Mission A			Mission B		
GPS Base Station	Beijing (BJ)	Hebei (HB)	Anyang (AY)	Beijing (BJ)	Zhengzhou (ZZ)	Anyang (AY)
Distance to Anyang	451 km	212 km	–	451 km	150 km	–
Receiver Type	Thales *Sagitta*	*Trimble 4600*	Ashtech *Z-Xtreme*	Thales *Sagitta*	*Trimble 5700*	Ashtech *Z-Xtreme*
Numbers of value	7	5	7	7	7	7
Reliability	good	bad*	good	bad**	good	good
Date	19/11/02		18 & 19/11/02	03/01/03		
Period	about 2 hours			about 5 hours		

* Recording of P2 and D2 was not possible.
** The receiver at Beijing GPS base station was not able to record data in a long period.

Tab. 3: Boresight alignment data of two days.

Date	Roll (deg)	Pitch (deg)	Yaw (deg)	RMS_{Roll} (deg)	RMS_{Pitch} (deg)	RMS_{Yaw} (deg)
18/11/02	0.1912	0.3679	0.9379	0.0105	0.0038	0.0032
19/11/02	0.1946	0.3607	0.9412	0.0071	0.0034	0.0039

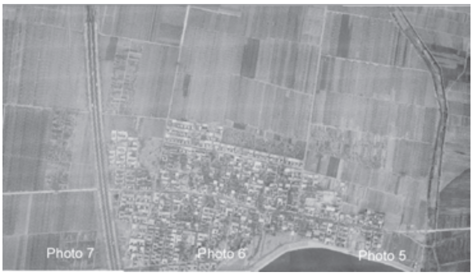

Fig. 5: Orthophoto mosaicking based on direct georeferencing.

the calibration field delivers reference data for the boresight alignment and thus, EO parameters of all photos of the block can be derived based on the calibration data. In our case we adapted the digital AT software *GeoLord-AT* (made in China) for the special task in the very short time and achieved satisfactory results. Tab. 3 shows the boresight alignment data of two days of the Anyang project.

To quickly check the quality of EO parameters determined by direct georeferencing

Tab. 4: Mode for accuracy analysis.

Mode	Description
AT	Aerial Triangulation
DG	Direct Georeferencing based on DGPS/IMU data
ISO_0	Integrated Sensor Orientation based on DGPS/IMU data only
ISO_4	Integrated Sensor Orientation based on DGPS/IMU data and 4 GCPs

Tab. 5: Accuracy comparisons with respect to 1 : 1000 scale mapping.

Case	Mode	Checks point	RMS (m)				Max (m)	
			ΔX	ΔY	ΔDistance	ΔZ	ΔDistance	ΔZ
	AT*	33/17	0.118	0.095	0.151	0.069	0.336	0.127
A 18	DG	116			0.204	0.139	0.520	0.428
	ISO_0	47	0.109	0.086	0.139	0.105	0.324	0.241
	ISO_4	43	0.107	0.086	0.137	0.106	0.309	0.223
	AT	31/15	0.091	0.067	0.113	0.078	0.236	0.124
A 19-AY	DG	109			0.244	0.197	0.540	0.604
	ISO_0	45	0.104	0.082	0.133	0.078	0.242	0.177
	ISO_4	41	0.115	0.089	0.146	0.078	0.255	0.152
A 19-HB	DG	109			0.389	0.521	0.609	1.004
	ISO_0	45	0.163	0.335	0.373	0.419	0.557	0.553
	ISO_4	41	0.136	0.093	0.165	0.099	0.344	0.193
A 19-BJ	DG	109			0.291	0.191	0.475	0.659
	ISO_0	45	0.149	0.221	0.267	0.116	0.412	0.374
	ISO_4	41	0.138	0.095	0.168	0.114	0.356	0.238
CHN-GB					0.5	0.25	0.5**	0.25**

* 13 planimetric and 29 vertical ground control points were used for conventional aerial traingulation. Annotation of check points indicates ‘‘planimetric/vertical’’

** value used for stereo plotting

orthophotos were generated by using a CASM own software. Fig. 5 shows an example of orthophoto mosaicking thereof. No remarkable EO parameter errors were found.

5 Results and analysis

To prove the applicability of the DGPS/IMU technology for topographic mapping in China we chose four modes for accuracy analysis (Tab. 4). Corresponding Chinese national specifications of photogrammetry for topographic mapping (cf. CHN-GB) were used as references. For missions A19 and B individual GPS base stations were treated separately. Due to some problems while data recording during the mission B data acquired at the Beijing base station was not used for the analysis. Tabs. 5 and 6 show the results of individual missions obtained by different modes. Reference values from Chinese national specifications are also given. According to the tables DG would be able to meet the accuracy requirements of direct mapping, e.g. orthophoto generation. However, there are some obvious weakness in the vertical determination. In comparison to AT results ISO_4 delivered the best fit even for the case A19-HB, in which problems occurred at data recording (cf. Tab. 2). Even ISO_0 could improve the results considerably. An important finding would be that the distance of the GPS base station to the mission area wouldn't deteriorate the quality of orientation considerably. The results shown in Tab. 6 were obtained under deadline pressure at that time and a systematic offset in vertical direction could be seen obviously. Therefore, further investigations need to be carried out in the future.

Another important issue is the efficiency when using the new techniques. Tab. 7 gives the schedule for the mission A from system installation to orthophoto generation this time. Since there was a lot of time spent for new system training, aircraft montage strategies and GCP measurements more efficiency could be expected in the future.

Since the blocks of the Anyang project were too small to find out a real statement about the cost in both time and money, we can only estimate a number of about 25 % saving in both time and money based on our tests this time.

Tab. 6: Accuracy comparisons with respect to 1 : 5000 scale mapping.

Case	Mode	Checks point	RMS (m)				Max (m)	
			ΔX	ΔY	ΔDistance	ΔZ	ΔDistance	ΔZ
B-AY	AT*	20/8	0.625	0.737	0.966	0.234	1.618	0.381
	DG	88			0.984	1.330	2.327	2.592
	ISO_0	32	0.578	0.535	0.787	0.981	1.403	1.797
	ISO_4	28	0.707	0.623	0.942	0.535	1.724	0.975
B-ZZ	DG	88			0.988	1.035	2.188	2.616
	ISO_0	32	0.496	0.610	0.786	0.820	1.575	1.667
	ISO_4	28	0.672	0.604	0.903	0.874	1.738	1.714
CHN-GB					1.75	1.0	1.75**	1.0**

* 13 planimetric and 16 vertical ground control points were used for conventional aerial traingulation. Annotation of check points indicates ''planimetric/vertical''

** value used for stereo plotting

Tab. 7: Schedule of the Anyang Mission A: From system installation to orthophoto generation.

Date	Place	Main events and actions
Nov. 16	Beijng Anyang	• About 5 hours drive from Beijing to Anyang and arrival in Anyang at 13:30 • Preparation for system installation in the aircraft • *WinMP*, *CCNS* training
Nov. 17	Anyang	• Airborne equipment installation and ground test • GPS base station training and test operation • *WinMP*, *CCNS* pilot training • Calibration field preparation (GPS measurment)
Nov. 18	Anyang	• Flight mission • *GrafNav* and *AEROoffice* training and mission data processing • Film transportation to Beijing
Nov. 19	Anyang Beijing	• Flight mission • *GrafNav* and *AEROoffice* training and mission data processing • Back to Beijing
Nov. 20	Beijing	• Film development and scanning • *AEROoffice* training and mission data processing • *GeoLord-AT* software adaptation for DGPS/IMU data handling
Nov. 21	Beijing	• AT of calibration field, boresight alignment and AT program adaptation • *AEROoffice* training
Nov. 22	Beijing	• AT of calibration field, boresight alignment and AT program adaptation • *AEROoffice* training and direct georeferencing of block A 18 • Orthophoto generation and mosaicking based on DG

6 Conclusions and outlook

Our first experiences described proved the applicability of the *CCNS/AEROcontrol* system for topographic mapping in China. According to our findings this time direct georeferencing would be suitable for direct orthophoto generation even of large scales. Integrated sensor orientation using a limited number of ground control points can compensate some systematic errors and makes the best way to replace the conventional aerial triangulation. For small scale mapping direct georeferencing should be good enough to meet the accuracy requirements.

Further investigations on the DGPS/IMU technology are planned in order to collect enough first-hand material e.g. to work out the corresponding National Standards and Specifications. We can now expect that this new technology will find a wide variety of applications in China soon.

Using digital aerial camera and airborne laser scanner (LIDAR) mounted on a unique platform supported by DGPS/IMU technology and making use of the global DGPS networks (e.g. GAO et al. 2002) it is to be expected in the near future that spatial information would be deliverable within 24 hours from its acquisition (TANG 2004).

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