THE DIGITAL MAPPING CAMERA DMC AND ITS APPLICATION POTENTIAL

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ABSTRACT:

The Hansa Luftbild Group decided in summer 2005 to purchase the Digital Mapping Camera (DMC) of Z/I Imaging (Intergraph) and is operating this system since February 2006. Up to now there was about 300 hours of aerial survey flights flown and about 30.000 images processed. Additional experiences exist with other large format cameras.
This paper will first give some information about the technical and financial processes of evaluation of the digital large format camera for aerial surveys. In the second part, the configuration of the system as it was chosen by Hansa Luftbild will be explained. The emphasis will be laid on the installation of the system in different kind of survey planes. The handling of the amount of data and the image post-processing are challenging tasks which demand a strict workflow and an integration into the complete project management workflow. Solutions for intermediate quality checks have been established and some are still under preparation.
Experiences about geometric and radiometric quality and calibration procedures can be demonstrated in the real production environment. The full potential of the DMC system is demonstrated at several applications.

RÉSUMÉ :

Le Groupe Hansa Luftbild a décidé à l'été 2005 d'acheter une caméra numérique DMC de Z/I Imaging (Intergraph) et utilise ce système depuis février 2006. Jusqu'à mars 2007, 300 heures de vol ont été effectuées et environ 30.000 images ont été traitées. Des expériences additionnelles ont aussi été effectuées avec d'autres caméras à grand format.
Cet article donnera premièrement de l'information sur les procédés d'évaluation technique et financière de la caméra numérique grand format pour les levées aériennes. Dans la deuxième partie, la configuration du système choisie par Hansa Luftbild sera expliquée. L'emphase sera mise sur l'installation du système dans différents avions. La manipulation de la quantité de données et le traitement des images sont des taches difficiles demandant un processus strict et une intégration dans le processus complet de gestion de projet. Des solutions pour le contrôle intermédiaire de la qualité ont été développées et d'autres sont en préparation.
Finalement, les résultats d'expériences sur la qualité de la géométrie et de la radiométrie dans un environnement réel seront exposés.

1. INTRODUCTION

The workflow of the photogrammetric production from the analytical to the digital processing started to change about 20 years ago with the introduction of the first digital photogrammetric stereo workstations. High precision film scanners followed with efficient productivity by auto winding systems. So it was only consequent when at the ISPRS Congress 2000 in Amsterdam the first large format digital aerial survey camera was introduced by Leica (see Sandau et al., 2000). Since that date mainly three major suppliers are dominating the market of the large format camera systems. Although there are more and more medium format cameras (about 40 Megapixels) using color CCD sensors based on the Bayer-pattern filter for reasons of geometric and radiometric precision here there will be a restriction for the multispectral approach.
The Hansa Luftbild Group got already 10 years ago first experiences about digital camera systems with a color line scanning system. Due to the limited format of the CCD line the applications were very restricted. In 2002 an EU IST research project entitled "GEOPIE – Geo-Referencing via Parallel Image Engineering" started and some more experiences during the project phase of 2 years could be gathered with a sophisticated combination of small CCD arrays (see Mayr/Ohlhof, 2004). Further more since 2003 began the use of the medium format camera system Emerge integrated into a LiDAR system. Also, here the restrictions of the quite small array format for small areas led to the demand of a large format digital camera system.
At the end of the year 2004 Hansa Luftbild decided on a technical evaluation of the existing digital large format camera systems (see Mayr, 2004).

2. EVALUATION PHASE

In the year 2004 there were only 3 large format systems on the market originating from major suppliers: ADS40 (Leica), UltraCAM-D (Vexcel) and DMC (Z/I Imaging). Consequently, the evaluation concentrated mainly on these systems, although other systems like 3-DAS (GeoSystem, see Wehrli et al., 2004) and DiMAC were taken into consideration initially. Besides some very detailed technical aspects the main criteria for the evaluation were:

- Line Scanner vs. Frame technology
  - Market research
  - Internal and external workflow
- Technical criteria
  - Technical evaluation
  - Compatibility to existing flight configuration

- Compatibility to existing internal workflow
- Return on investment
  - Investment plan
  - Financing
  - Economic aspects – break even point

A market research found that 80% of the aerial survey flights undertaken for our clients are for their own production and the vast majority of our clients clearly prefers frame technology. Their argument mainly was their own production process coming from traditional analytical photogrammetry. The same appeared to our own internal production workflow. Also, all existing software here is based on frame images, and a change of the whole system would end up in high additional investments, as well financially, operationally and educationally.
On the technical side the criteria of compatibility with respect to our existing environment in 6 of our aerial survey planes under use were very important. An easy exchange of sensor equipment must be guaranteed. As the company operates since decades systems from the former supplier Zeiss the best compatibility was given with the DMC from Z/I Imaging - Intergraph. The technical evaluation took also the quality of the images into account. But as this topic was a matter of permanent changes in the calibration and post processing procedures an evaluation was quite difficult. During the year 2005 about 20.000 digital images of the large format camera system UltraCAM-D could be processed for aerial triangulation and the production of digital orthophoto mosaics, and this brought a lot of experiences too.
Ground coverage with same GSD was another evaluation criterion. Here, UltraCAM-D covers 80% of the DMC's ground coverage, which results in an economical disadvantage.
The final evaluation step was the determination of the return on investment and the break even point. As well a comparison between the analog and the digital camera system was done. The analysis under the assumption of use of film material, film processing, film scanning, etc came to the result that the break even point is at about 150 h of use of the camera system per year. The investment is not only restricted to the camera system. The necessary computer hardware for data processing and storage, the high speed data network, the back-up systems, etc and the total costs for training have to be added. In total the relation between the investments in camera system, computer hardware and training was about 7:2:1.
After the decision for the DMC system the contractual negotiations with the supplier started and the following schedule was realized:

- Sep 2005 signature of the contract
- Nov 2005 installation of processing system and training
- Dec 2005 delivery of the DMC and first test flight
- Jan 2006 camera training phase
- Feb 2006 start of production phase

A technical description of the camera system can be found in Hinz et al., 2001, Dörstel, 2003 and first results in Schroth, 2007a.

3. CONFIGURATION

The general configuration of the aerial survey system is shown in figure 1. It is modular and consists of the navigation and flight guidance system CCNS4 (IGI), the inertial measurement unit AeroControl (IGI), the differential GPS and the DMC (Z/I Imaging, Intergraph) with the stabilized mount TA-S (Z/I Imaging, Intergraph). The modularity is important because other sensors like analog aerial survey cameras, LiDAR, thermal sensors etc have to be repeatedly and project dependent installed into the survey planes.

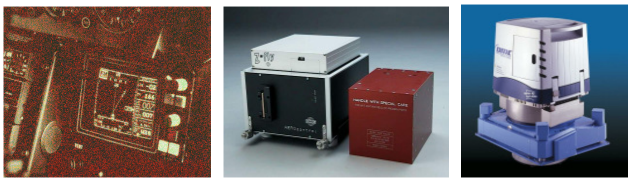

Figure 1. System configuration with flight navigation system CCNS4 (IGI), GPS/INS (IGI), DMC (Intergraph)

Digital images are stored during flight mission in the so called flight data storage system (FDS) comprising 3 storage devices with a total capacity of about 2.200 images. The capacity is more than enough for one day of survey flight. After each day the FDS is copied via the copy station, a computer with a fast I/O bus system and prepared for a rough environment. For safety reasons all the data are copied independently twice onto hard disks. These hard disks are copied via fire wire 800 connection later on in the office to the image server system, a data storage system with a capacity of more than 100 TB on RAID array systems. Figure 2 shows the appropriate devices.

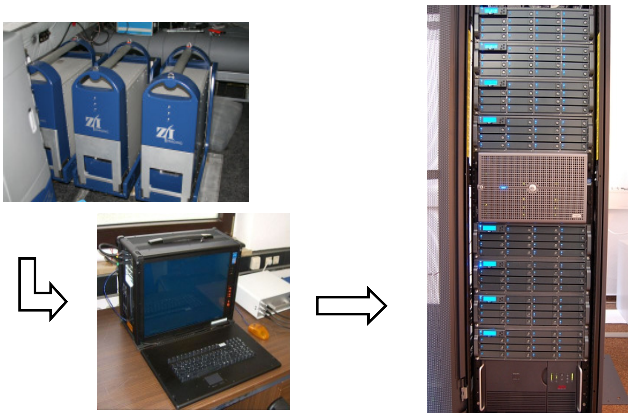

Figure 2. Data flow from flight data storage system via copy station to image server

For the post processing of the raw image data a high performance server is available. One can remote control it via internet using a VNC terminal connection. The post processing server is equipped with 4 processors to speed up the processing time (see Dörstel et al., 2005). Our analysis of the processors, however, showed that only two of them are in use during the processing time. This leads to the assumption that the current version of the post processing software (PPS) is not designed for a multi-processor system. The intermediate images are stored on a raid array system connected to the PPS server. The final panchromatic, rgb- and CIR-images are delivered to the image server via fiber channels. All servers are connected by parallel GigaBit switches (4-times). The image server controls the data storage in the storage area network (SAN) with several RAID systems. Figure 3 shows a graphical description of this configuration. For backup two tape robot systems, based on LTO-3 tapes are integrated, each equipped with 36 slots. To speed up the data transfer rate the upgrade to a 10 GigaBit network is planned for 2007.

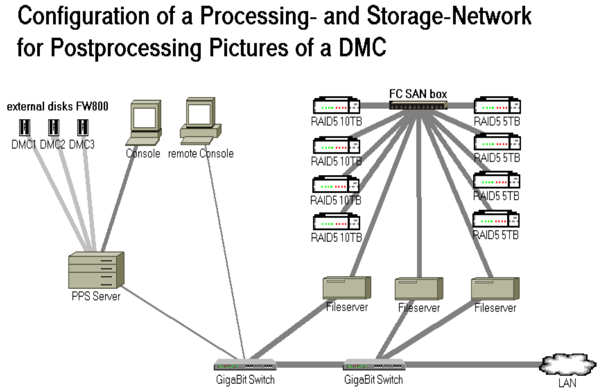

Figure 3. Processing and storage network of DMC post processing

The processing time for the complete post processing of the raw image data to the final image data varies between 2 and 3 minutes per image under this configuration. This means for 2.000 images with an average processing time of 2,5 minutes the pure processing time is 80 hours or about 3 days (which, by the way, is less than the classical film development plus scanning). With all the preparatory work, adjustments, testing, etc one can estimate one complete week for the whole procedure. For the purpose of on-site evaluation and determination of the final images, e.g. in remote areas, a second PPS license is available on the mobile copy station.
A quality control procedure accompanies the whole workflow of the image generation. During the aerial survey flight the storage of the image data onto the FDS is controlled and quick view images are checked on a notebook. After the arrival the images are checked again with the FDS viewer software and some sample images are processed on the copy station. For the post processing procedure the image information is automatically prepared out of the CCNS4 information by a self developed process to avoid mismatching problems in the numbering system etc. After the post processing of the images a first radiometric check will be done. In a further check the flight operator is producing the flight reports. Besides the radiometry the parameters of side lap and end lap, the drift and the image quality are controlled. The quality check of the GPS/INS data will be done during the adjustment process for generating the parameters of the exterior orientation.

4. EXPERIENCES AND PRACTICAL APPLICATIONS

Since February 2006 the DMC system was permanently under use. It produced 30.000 images till March 2007 and executed more than 300 hours of aerial survey flights. The camera has been operated in Germany, The Netherlands, Belgium, France, Spain, Italy, Austria and Romania. During this time there was only one electronic failure with a power supply unit which caused a one day repair at Z/I Imaging; in December 2006 an update of the camera firm ware and the radiometric calibration was done. Most of the projects were for the production of digital orthophotos in combination with automatic DTM generation, only 10 % for stereo restitution. For the majority of the projects an aerial triangulation was used for geo-referencing. This was done mainly for purposes of quality control and to obtain experiences of the geometric quality of the camera. The results with the integrated IMU system (see Schroth, 2003) were very promising and showed out of the determination of the bore sight alignment with test areas a high stability and accuracy. Besides this information some effects in the geometric and radiometric characteristics of the camera could be observed.

4.1 Geometry

Aerial triangulations were undertaken with the software packages MATCH-AT (Inpho GmbH) and PAT-B. However, the results of the achieved accuracies were different to the theoretical expectations. For smaller blocks of some hundred DMC-images, also corridor shaped blocks (strips), the results were of the same quality as with analog cameras and as expected (see also Dörstel et al., 2003 and Madani et al., 2004). Further, the 12 bit per pixel registration of the grey values increased the number of matched tie-points and thus the geometric stability of the block. However, for larger blocks, i.e. more than some hundred DMC-images, systematic effects appeared. This can be clearly shown at the following example (cf. Schroth 2007b).
For the production of true ortho images the city of Gent/Belgium was flown with the DMC in summer 2006. The flight line index can be seen at figure 4. The photogrammetric block size is 5,5 km * 8,5 km covered by 1.105 images in 29 strips with a GSD of 7,2 cm which is equivalent to a photo scale of about 1:4.000 (analog camera). Due to the true ortho image production the end lap was chosen by 60 % and the side lap by 80 %. There are 53 ground control points, well distributed on the perimeter and inside the block, and the coordinates of the projection centers were observed by a DGPS/INS system.

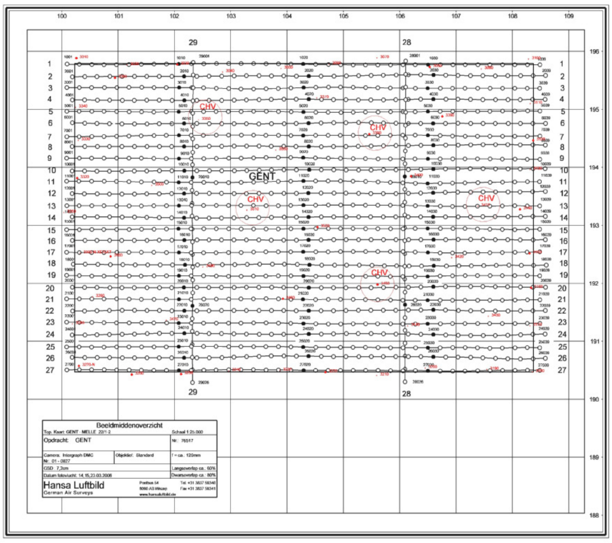

Figure 4. Flight line index of the block Gent

For analyzing the aerial triangulation 14 ground control points in the center of the block were selected as independent check points where the differences between their in the terrain measured and photogrammtric adjusted coordinates were used to derive the RMS values (root mean square values). The a priori standard deviations of the coordinates of the ground control point and the projection centers can be seen in table 1.

Standard deviations	x	y	z
Ground control points	0,030 [m]	0,030 [m]	0,030 [m]
Projection centers	0,050 [m]	0,050 [m]	0,050 [m]
Image points	0,002 [mm]	0,002 [mm]	

Table 1. A priori standard deviations for the photogrammetric block adjustment

Table 2 shows the different block types and their description and table 3 the results of the different approaches of the aerial triangulation. First the overlap between the strips has been varied between 20 and 80% and second the adjustment was done with or without additional parameters. As parameter set for self-calibration the Grün approach was chosen (see Grün, 1978).

block type	# images	# strips	end lap p [%]	side lap q [%]
1-fold	364	10	60	20
2-fold	442	12	60	40
3-fold	598	16	60	60
4-fold	1.105	29	60	80

Table 2. Block type description

block type	without add. parameters RMS			with add. parameters RMS		
	x [m]	y [m]	z [m]	x [m]	y [m]	z [m]
1-fold	0,019	0,031	0,109	0,019	0,034	0,064
2-fold	0,038	0,020	0,107	0,031	0,016	0,050
3-fold	0,018	0,034	0,118	0,019	0,034	0,048
4-fold	0,024	0,030	0,593	0,020	0,034	0,030

Table 3. RMS values from 14 independent check points

The results clearly demonstrate systematic effects in the block for the height coordinates. The planimetry is perfect and not changing due to block geometry nor use of additional parameters. It can also be seen that a standard block configuration with p = 60% and q = 20% indicates that there are some effects at the z-coordinates but it is difficult to prove their existence and significance.
A different selection of the independent check points came to the same results and proved that there is no influence of the geodetic network or of the ground control measurements. The effect at the z-coordinate with the 4-fold block type is still under evaluation.
The significance of systematic effects influencing the height accuracies was also shown by Alamús et al., 2005 and 2006. One can handle this in various ways, e.g. introduction of additional parameters in the aerial triangulation (see Jacobsen, 2006b and 2007), use of more ground control points and partially by a higher accuracy of the coordinates of the projection centers. But these approaches only control the effects. They do not solve for the origin of the problems. As it seems that for other large format cameras working with a combination of several camera heads (see Jacobsen, 2006a and 2007) these systematic effects are symptomatic too, the mathematical models for the use of these systems are not yet good or adopted enough under the aspects of high accuracy. Further, for as long as adopted math models are available in aerial triangulation only and are not cross-vendor-wise implemented in commercial applications, such math models would be for pure academic value. Common to all major digital frame cameras is their rectangular image format. However, software-wise implemented additional calibration parameter definitions were often based on square-sized, analog aerial imagery. Thus, further and intense research and analyses are necessary as it was done for decades with the analog camera systems. The suppliers are also developing and improving constantly their calibration procedures in order to offer a better definition of their respective camera geometries.

4.2 Radiometry

Besides the challenges in the camera geometry there were some deficits in the radiometry too. There are effects which are characteristic for digital cameras such as the total reflection e.g. on white surfaces or on glass surfaces such as roof windows, winter gardens or green houses (see figure 5). In some cases the color representation of the blue channel had a bias (see figure 5). It is assumed that during the process of the pan sharpening an influence from the panchromatic band causes this effect. The panchromatic band covers and stores parts of the near infrared band for better visibility of topographic objects, which is very supportive in data compilation work. The biasing effect mainly appeared during the vegetation break out and when high concentration of chlorophyll in the plants were present. The camera got a new radiometric calibration in December 2006 and an update of the post processing software should avoid these effects in the future. Smearing effects at sharp edges (as can be seen at roof tops at figure 6) are no more appearing since December 2006 release.

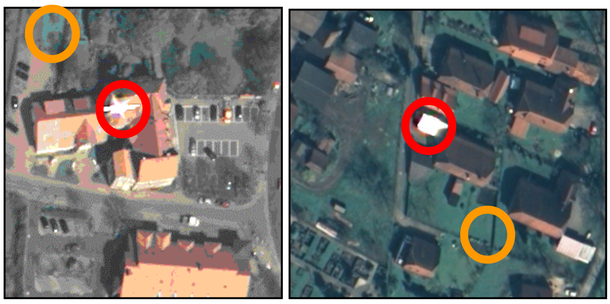

Figure 5. Radiometric effects of total reflection (red circles) and influence of the near infrared on the blue channel (orange circles), flight for Land Survey Department Lower Saxony

Another effect in the radiometric quality appeared during the automatic classification of the color infrared images. This was analyzed by Microsoft Netherlands, International Remote Sensing, during a research project. They displayed the near infrared channel in the red band of the rgb composite. In water zones which should be more or less homogeneous, some kind of hot spots appeared after linear stretching of the red band (see figure 7). This effect seems to be a reflection of the shutter of the NIR band, but according to the supplier this is in the range of the technical specifications of the camera.

Figure 6. Smearing effects at roof tops before December 2006 release

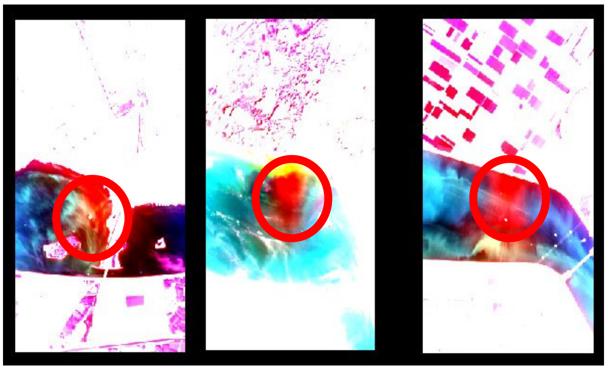

Figure 7. Hot spot effect in the near infrared

Besides these challenging experiences in geometry and radiometry which were mainly solved in a first step by developing our own procedures to fulfill the contract obligations with our clients we got very promising results with the DMC system as it can be seen in the examples of the figures 8, 9 and 10.
Figure 11 shows the high potential of the camera very well in the enlargement of one image where one can recognize the driver of an open-topped car.

5. CONCLUSIONS

The introduction of a new technology into an existing production environment confirms to remain always a challenging task. The best compatibility to the existing workflow and a clearly scheduled integration and training period guaranteed the fastest way to productivity. The digital metric camera system DMC could already prove during its first year of operation a clear economic advantage, although the necessary investment was very high compared to the former analog aerial survey camera systems. As with all sophisticated technical systems there are some challenging aspects which have to be handled in an adoption and optimization of the production workflow and in an improvement of the system technology by itself. Also the use of analog film cameras is not a totally safe process and is facing on and off with technical problems.

Figure 8. Color infrared image with GSD = 0,25 m, southern Spain

Figure 9. Color image with GSD = 0,25 m, port of Hamburg

Figure 10. Color image with GSD = 0,07 m, city of Gent, Belgium

The market demands for digital large format cameras are growing. Further, the images of an aerial survey flight come more and more in the front as simple rectified images, ortho images or ortho mosaics. Demand for stereo restitution for mapping purposes clearly appears to decrease. Thus the radiometric image quality is more important than before. Many of the digital camera systems are designed for 12 or more bits per pixel and band, but many of the viewing systems are not yet prepared for this. As well the amount of data to be handled is often underestimated. To get the most benefit out of the new technology this demands for a close co-operation between the system suppliers, the service providers and the users.

Figure 11. Enlargement of color image with GSD = 0,06 m (original at the upper left corner)

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