TRENDS IN DIGITAL PHOTOGRAMMETRY FROM AN INTERNATIONAL ENTERPRISE PERSPECTIVE

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ABSTRACT:

The internet hype for aerial and satellite images, kicked off by Google (Google Earth), Microsoft (Virtual Earth), and others, is giving the Photogrammetry, Remote Sensing, and GIS markets a tremendous exposure. Making the complete land coverage of Earth in the shortest time could only be achieved by satellite imagery. However, the growing demand for more and ubiquitous details in urban and developing zones can be achieved by aerial images of very high resolution. These internet providers made the idea of geo-referenced images very popular and extended the traditional geospatial market by opening the access to this data for different applications and thus created the now well-known geospatial web portals. As many of them, frequently and for cost reasons, make use of archived images or second-hand images. Professional users, driven by the needs of their businesses and engineering applications, are in demand for highly accurate and up to date geospatial information. So, the internet earth data providers are indirectly pushing the traditional markets, as well. These growing markets cause a very rapid development of image data acquisition systems and expanded geo-referencing applications. In this paper, the process of high resolution aerial images, capturing from the point of view of a service enterprise working in many different geographic regions, is discussed. Proven techniques in combination with highly automated workflows show process chain optimisation potentials in all known business aspects from planning, preparation, execution, to archiving of geospatial mapping projects. We put special emphasis on the economic use of available image sensor techniques and their integrations. Modern flight mission planning helps reduce flight execution time while optimising demanded along track and across track overlaps. 3D-modelling is one of the key elements of this advancement, and we discuss this aspect to some extent. Properties of the different digital large format camera systems have impact on the flight mission planning as well as the execution and thus require an adaptation from the traditional square-formatted pinhole camera model. How far new digital camera and scanner designs have impact on block geometry and accuracy are another aspect to be considered. Well known film development gets substituted with ground-processing, also called post-processing. The nature of the digital sensors deserve particular consideration when this technology is implemented in an internationally operating mapping company. Often times, international operations require additional logistics aspects to be taken care of, some of which will be presented in this paper. Customer’s required ground resolution product ultimately drives a number of decisions and it will impact the planning phase or even before that such as consulting phase with the client who very often appears being uncertain what actually is needed for his particular application. Ultimately, archiving and retrieval of geo-spatial data is an important aspect to consider as well. For the safety of project execution, interim archiving steps should be integrated into the workflow. The resulting demand in storage and the capability to transfer large quantities of image data from one department to another department within an enterprise environment quickly put significant technical and economical demands on in-house infrastructure.

1. INTRODUCTION

Aerial image data acquisition, its processing and the total photogrammetric work flow (see figure 1) changed dramatically during the last decades. It started with analogue to digital conversion of aerial images by means of high resolution film scanners about 20 years ago and was followed by the first operational digital photogrammetric workstations. Surprisingly it took more than 10 years to exploit the full potential of digital or digitised images by automatic processes integrated into the work flow. Before this transition succeeded one applied the traditional analogue/analytical processing mimics in the digital environment. In parallel to this work flow evolution the development of the Global Positioning System (GPS) and the Inertial Navigation Systems (INS) revolutionized the total process of aerial survey. And since large format digital cameras are operational fully integrated and purely digital processes are possible. They influence the production work flows as well as the traditional market structures (see Schroth, 2008).

Thus the paper will focus on the potentials of process optimisation but also on experiences with latest frame image sensor technologies. Image data acquisition, their post processing, geo-referencing and mass data handling are high lighted (see figure 2 about the sub-process of the aerial survey flight).

These new technologies influence the managerial and administrative processes especially in international projects which will be shown finally.

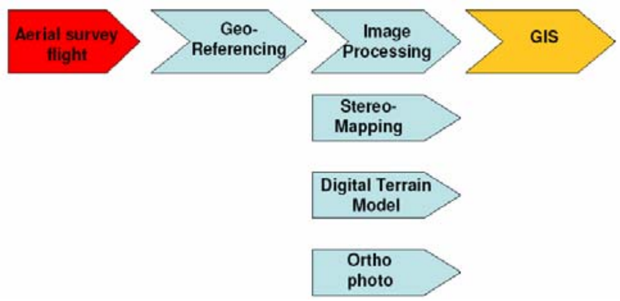

Figure 1. The total photogrammetric workflow

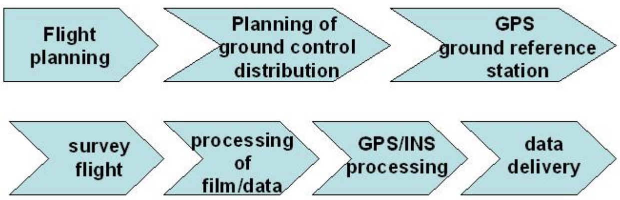

Figure 2. The sub-process of the aerial survey flight

2. PROCESS OPTIMIZATION

2.1 Flight Planning and Navigation

Aerial survey flight planning is still a challenging process. Although rough Digital Terrain Models (DTM) are more or less worldwide available an accurate planning is essential. This holds especially true for the high standards asked for with respect to the overlap situation of the images. Optimisation can be achieved when 3-dimensional flight mission planning software will be used like IGIplan (IGI) or Z/I IN-flight (INTERGRAPH). So an interactive planning of the flight lines and the overlaps under the conditions of the specific imaging sensor can be achieved (see figure 3).

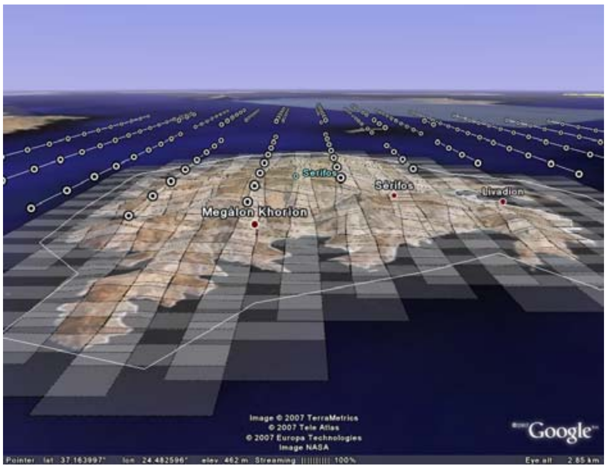

Figure 3. Flight lines in a 3-dimensional presentation (source: IGI)

With the integration of e.g. Google Earth for superimposition the flight lines and the exposure centres can be easily visualized and made understandable to non-specialists, often found on the ordering party side.

The aerial navigation and the pin point exposures have been strongly optimised by the assistance of the Global Positioning System (GPS) since many years. Accurate navigation but also a precise camera control are available (see Arnold et al., 1993). Additionally an accurate heading of the camera is assisted nowadays by the Inertial Measurement Unit (IMU), based on the INS. Roll and pitch are controlled by the stabilized mounts of the sensor.

2.2 Raw Image Data Processing

For analogue film cameras the processing reached a high quality standard. Nearly clean room conditions in the processing facilities are necessary. With the use of digital cameras there is no need for any film processing and film scanning. So there are no influences on the image quality by chemical and physical effects anymore and the demands for the production environment are significantly less. Nevertheless, some infrastructure, e.g. high speed networks, partly is needed and imposes other kinds of complexities in daily operations. The raw image data post-processing substituted the former film processing in some ways. So, there still is some sort of “digital image development” and it accounts to the total time budget of a survey flight.

2.3 Geo-Referencing

The geo-referencing of the image data has been improved dramatically. Direct (GPS/IMU), indirect (aerial triangulation) and integrated (GPS/IMU assisted aerial triangulation) geo-referencing are in use, depending on the demands of accuracy, resolution, terrain conditions and the quality of the geodetic network. The economic effect of these improvements are shown in Schroth, 2007b. To achieve highest geometrical accuracies with the new digital sensors in chapter 4 a detailed description is given.

2.4 Process Automation

The further image processing is highly influenced by the research and development in image matching techniques (see e.g. Förstner, 1998). Process steps could be nearly fully automated. Especially mass point measurements like tie points for aerial triangulation or DTM measurements were improved by this in combination with sophisticated strategies for gross error detection and filter techniques.

So, the work flow from the indirect geo-referencing till the digital ortho photo mosaic is highly optimised. Only the typical feature collection by stereo plotting is still a cumbersome manual work. High resolution feature extraction methods are still not sufficient enough to fulfil the cartographic and GIS demands. Only the integration of manual 3D feature collection into geographic information systems is mainly solved (see e.g. Rosengarten, 2005).

3. PREPARATION AND PLANNING PHASE

The integration of digital frame camera sensors in the workflow causes some changes compared to the film camera systems. The following parameters are important:

- Ground sampling distance (GSD)
- Format of the image frame
- Overlaps

- Storage capacity on board
- Focal length of the camera heads
- Accuracies to be achieved

The definition of the necessary GSD is the most crucial item, if one compares it to the film camera system with the common image scales. As there is no direct mathematical relation between both sensor types, the GSD will be mainly defined by the accuracies to be achieved. In combination with the overlap definition, the dimensions of the image frame and the GSD the necessary flight lines and the number of images will be defined. The limiting factor of the digital sensor is the minimum image sequence. As these sensors have a rectangular format the maximum forward overlap is a function out of the velocity of the airborne platform, the minimum discharging time of the CCD's and the GSD or flying height. If there is a high overlap necessary, e.g. for the generation of true digital ortho photos (TDOPs), it is recommendable to increase the side lap, too.

The necessary on board storage capacity is a function of the GSD and the forward overlap. For example a DMC sensor (see chapter 4) flown for a GSD of 7 cm with a forward overlap of 60 % needs for a typical aerial survey mission time of 2 hours a capacity of about 610 GB:

Cap. = 280 MB * (2 * 3600 s * 65 m/s) / 215 m = 609.500 MB

whereas
280 MB per exposure (raw data, rgb, nir)
65 m/s speed of the plane
215 m base line.

For the achieved accuracies the similar geometric conditions are applicable as for the film cameras. Ground control distribution, use of GPS/IMU and the overlaps are following the same mathematical models. Only for the height accuracy the special generated virtual images out of several camera heads, the small aperture angle of the cameras and the base to height ratio are causing results more or less known from the 300 mm film camera. Special calibration procedures (see chapter 4) should improve the camera geometry.

Digital image sensors are sensitive of reflections at glass, e.g. green houses, winter garden, roof windows, cars, etc. But also in low textured zones like sand desserts irradiations can occur. To avoid the total reflection survey flights at lower sun angles are recommendable.

4. DIGITAL IMAGE SENSORS

This chapter focuses on large format digital frame cameras. In order to avoid an increase of flight strips and thus costs on one side and to maintain proven geometric image block constraints on the other side, digital frame cameras have to cope with rock solid film camera technology. This points to DMC of INTERGRAPH and UltraCam-X of VEXCEL, see figure 4. Both digital frame cameras attempt to substitute film cameras.Table 1 shows major properties of these 3 camera representatives.

Interesting enough, both digital large format cameras possess far weaker base-to-height ratios than classic film cameras. Actually, DMC and UCX compare in this respect with a film camera of 300mm focal length, compare b/h of DMC/UCX with Film (300). This points out that DMC and even more UCX behave like normal angle cameras along flight direction. It is well known and theoretically shown, see Kraus 1982, that normal angle cameras (300mm) due to their small (weak) b/h ratio values possess compared to wide angle cameras (150mm) only half of accuracy in elevation measurements. The authors confirm this property experienced in many mapping projects conducted with aforementioned digital large format cameras.

Item	DMC	UCX	Film (150)	Film (300)
Panchromatic image size [rows x cols]	13,824 x 7,680	14,430 x 9,420	16,428 x 16,428	16,428 x 16,428
Panchromatic physical pixel size [µm]	12	7,2	14	14
Panchromatic lens focal distance, standard [mm]	120	100	150	300
Field of view along / across track [deg]	42 / 69.3	37 / 55	75 / 75	42 / 42
Color	RGB+ NIR	RGB+ NIR	RGB or CIR	RGB or CIR
Shutter speeds [sec]	1/300 to 1/50	1/1000 to 1/30	1/500 to 1/60	1/500 to 1/60
Forward motion compensation (FMC)	TDI	TDI	avl.	avl.
In-flight storage capacity	0.8 TB	1,7 TB	~500 img/film	~500 img/film
Image exposure mode	synchronous	a_synchronous, syntopic	synchronous	Synchronous
Capacity to collect in-flight uncompressed frames	~2,200	~4,000	~500	~500
Above Ground Level (AGL) [m] for 6cm GSD	600	833	645	1290
Swath width [m] for above AGL and 6cm GSD along / across	460 / 829	401 / 624	989 / 989	989 / 989
b/h ratio at 60/30% overlap along/across	0.31 / 0.97	0.27 / 0.73	0.61 / 1.07	0.31 / 0.54
Intersection angles [deg] along/across	17 / 44	15 / 36	31 / 47	17 / 28

Table 1. Overview and Comparison Digital / Film Cameras

Figure 4. DMC from Intergraph and UltraCam X from Vexcel

As can be clearly seen from table 1, the b/h ratio values are significantly better in across track view. This recommends to place ground control points preferably into strip overlap zones, since particularly then their elevation values might be determined with better accuracy than in along track only mode and thus support overall stability of the block.

It is reported in several user community meetings, that some apparently systematic properties appear in images with either digital large format camera system. Intergraph attempts to reduce the systematic effects with an additional calibration grid applicable to the post processed images. Results of improvement are not yet known to the authors, Vexcel tries to improve performance with additional temperature sensors and dependent parameterisation during post processing. Here the success of improvement is as well still unknown at time of writing this paper. It remains to be stated that, at time, the same, rock-solid operation and predictable accuracy as with film cameras is not yet achieved with digital large format frame cameras. Thorough, scientific research appears appropriate to be undertaken in near future.

Another aspect, more from a point of view of data processing, is the quantity of data. Table 2 shows a comparison based on an assumed block size of 10km x 10km, 60/30 overlap situation and a flying height appropriate for 6cm ground resolution.

Item	DMC	UCX	Film (150)	Film (300)
# Images	935	730	365	365
Data volume [GB]	739	740	275	275
# images ratio DigFrame / Film	2.6	2.0	1	1
Data volume ratio DigFrame / Film	2.7	2.7	1	1
# strips	17.2	16.5	14.5	14.5

Table 2. Image Quantities – Digital vs. Film

One clearly sees the big amount of storage space compared to film cameras. With respect to images, DMC generates 2.6 times as many images as a film camera, and UCX, due to its larger image, 2 times as many images. Nevertheless, both generate the same amount of data, which is 2.7 times more than a comparable film camera flight. The argument of low or no cost for digital images is close by. However, when it comes to production, one has to triangulate, DTM process, and last but not least seam edit ortho images for the mosaic. Based on above shown factors of more aerial images to process, DMC demands 2.6 times more efforts and UCX 2 times more than the same job done with film images. This ties human resources to a particular project and thus accounts for service charges.

The undoubtful positive sides of digital large format camera systems are, of course, image quality, multi-spectral data availability from one flight, no dust, no scratches in images, loss less copying, easier data handling in projects in foreign countries, bigger radiometric depth and thus more details in particular, in darker areas, no film development and thus avoidance of chemicals, no scanning, and last but not least the full digital workflow. These very positive properties encourage the authors to push the use of digital large format cameras. At the same time it appears urgent to get the systematic behaviour under better and repetitive control, since the geometric constraints, as shown in table 1, demand for a perfect numerical modelling in order to achieve highest possible accuracies, see publications from Cramer, 2007, Jacobsen, 2007, Schroth, 2007a and Wu, 2007. Certainly, the potential is there, the manufacturers are invited to show the user community how to.

5. IT STRUCTURE

This chapter exemplary describes the integration of a DMC digital sensor into the IT structure of the Hansa Luftbild.

Digital images are stored during flight mission in the so called flight data storage systems (FDS) comprising several storage devices with a total capacity of about 4.400 images with a DMC for example. The limiting factor is the number of storage devices on board. The capacity is normally 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 2 TB 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 150 TB on RAID array systems. Figure 5 shows the appropriate devices.

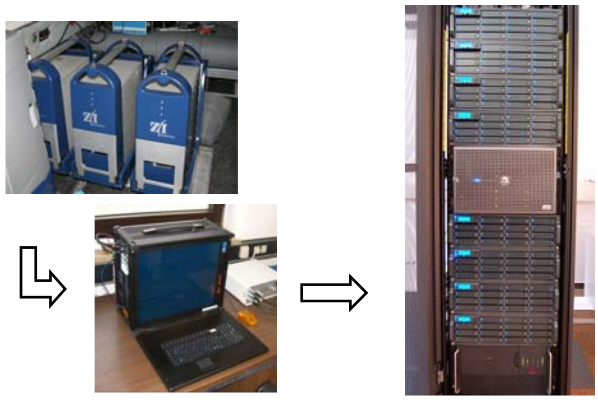

Figure 5. Data flow from flight data storage system via copy station to image server

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 for distributed processing (see Dörstel et al., 2005). The intermediate images of a DMC 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 6 shows a graphical description of this configuration. For backup and archiving 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 was necessary.

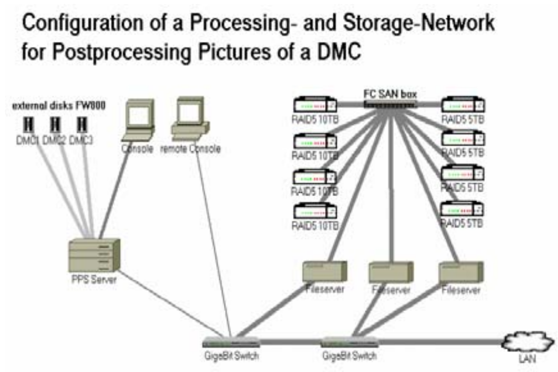

Figure 6. Processing and storage network of DMC post processing

The processing time for the complete post processing of the raw image data to the final image data is about 2 minutes per image under this configuration. This means for 2.000 images the pure processing time is 67 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 mobile post processing system is recommendable.

6. INTERNATIONAL OPERATIONS

6.1 General Conditions

International operations in the fields of image data acquisition and processing are always influenced by local administrative regulations. Technically there is a nearly worldwide accepted standard for the processes in general. Of course, there are some differences in the availability of the latest technologies.
The main differences are coming form different levels of security applicable to single national rules. An internationally operating enterprise has to respect some main regulations as shown in the following.

Certified Equipment for Aerial Surveys

In general the platform with the integrated sensors has to be certified by the national flight organisations. So called STCs (supplemental type certificates) are necessary. Then some high tech equipment like gyro systems are following restricted export regulations which is applicable for stabilized sensor mounts and inertial navigation systems. Time consuming applications for permits have to be taken into account. Logistic problems on site like access to the air fields, fuel supply, availability of security officers, storage facilities etc. are challenging each international mission.

High Resolution Images

The resolution of the digital images are more and more under discussion for security reasons and privacy protection. The definition of high resolution differs, one has to estimate special security procedures with GSD of 20cm or better, but still in many regions with any aerial image data. The image data post processing has to be done on site in protected zones. Also, deleting of the raw image data at the on board data storage system has often to be proven and certified.

So high performance mobile processing systems and security certified software can be necessary during international operations.

6.2 Challenges of Outsourcing

As mentioned in chapter 2 there are still processes in the photogrammetric work flow which are highly interactive. The labour costs are dominating the production costs. Here in many production environments outsourcing into low cost countries in Asia and East Europe are common. Thus a quick view on one of these markets, the emerging market of China, will be given.
During the last years the aerial survey and mapping industry in China has greatly developed and is flourishing never before under the stimulation of Web2.0, which made the aerial image no more mysterious and unreachable. It totally changed the market pattern of aerial image products. A lot of industries began to profit from aerial survey and mapping, which helps them to reduce the cost and improve the efficiency of project implementation. Driven by these big market demands, many GIS enterprise are established under the aid of venture capital in China, e.g. NavInfo Co., Ltd., Ritu Information Systems, Inc., AutoNavi Software Co. Ltd, Beijing Eastdawn Information Technology Inc and so on, some of them are equipped with more than 200 seats of digital photogrammetric workstations (DPWs) and work with outsourcing data processing projects from other countries (mainly form Japan) very successfully.

Also digital aerial survey services are very popular in developing countries and especially in emerging markets like China. For example, there are many large size digital aerial camera users in China. Till 2008, the Chinese aerial survey companies have bought 16 DMCs, 4 UCDs and 6 ADS40s. These systems are widely used in “the Second National Land Surveys”, urban and rural planning and infrastructure construction. Especially in Province Jiangsu, the Geodata of whole province has been updated with 10 cm GSD of DMC images, and these images are processed in DOP and large scale digital topographic maps.

Figure 7. SWDC system from China

In China, an own digital large format aerial camera system, named SWDC, was developed by Professor Xianlin Liu (see fig. 7). The SWDC consists of the camera system and the positioning system GPS/IMU. The camera lenses are changeable and three different focal lengths are available: 35mm, 50mm and 80mm. As there are many mountainous areas in China, the b/h ratio was designed suitable for reaching good height accuracy. At the side overlap 60%, the b/h ratios are separately 0.87, 0.59 and 0.31. Limited by the camera lenses and CCD-Sensor, the radiometric quality of SWDC-4 should still be improved.

There are mainly three photogrammetric software systems available, VirtuoZo, JX-4C and Intergraph Imagestation, which are widely used in China for DOP/TDOP production and stereo mapping. Recently, some Chinese enterprises have imported Pixel Factory Systems developed by Infoterra France to improve the workflow of photogrammetric processing and production's quality of DOP. More and more international enterprises are opening their data-processing centres in China for mapping and DOP/TDOP because of local low cost workstations and work labour.

7. CONCLUSIONS

With the full integration of the digital camera sensors the photogrammetric workflow has reached a high level of productivity. There are still some challenges in the field of sensor integration in the sub-process of the aerial survey flight to stabilize this cost intensive production step. Also the long term stability of the sensor geometry has to be analyzed and appropriate calibration procedures have to be established fulfilling the geometrical and radiometric aspects.

In integration into international operations is strongly influenced by national and local regulations, mainly caused by security and privacy aspects. But the availability of high resolution remote sensing data and their access via Internet portals will influence the situation in the near future.

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