'Photogrammetric Week 05' Dieter Fritsch, Ed. Wichmann Verlag, Heidelberg 2005.

Experience in Applying Matching Techniques Using Images from Digital Cameras

TOBIAS HEUCHEL, Stuttgart

ABSTRACT

Different digital frame cameras have been introduced in to the market and have established a base for a complete digital work flow for photogrammetric production. Digital Aero triangulation and DTM extraction provide a base in this process. The paper summarizes some experiences with the application of known matching techniques and demonstrates the performance of the available tools.

1. INTRODUCTION

The introduction of digital sensors into the photogrammetric image recording technology led to the utilization of different concepts. On the one hand large format digital frame cameras (multi-head sensors from Intergraph/DMC and Vexcel/UltraCam) were established as direct successors of large format aerial film cameras. But also digital cameras with smaller formats (4k x 4k, one camera head) found a market (e.g. Emerge DSS Mostafa (2003)) and the Three Line Sensor has proven it's concepts successfully in practice (e.g. Fricker et al 2005). A current overview about the status and development of digital sensors can be found in Cramer 2005.

Independently of the used sensor the photogrammetric data processing requires further automation. This applies also to aerial triangulation and DTM (Digital Terrain Model) extraction, because the amount of data to be processed increases with the number of photos quite fast. Projects with some thousands of photos are not uncommon anymore in production.

By the higher radiometric resolution of up to 12 bits one expects an influence on the matching procedures apart from a better image quality. To examine this influence on the matching a test area with extreme radiometric differences was searched for. One finds good examples of it in open mining areas. In such areas different topography is often present closely next to each other. Flat terrain areas (forest, fields, cultivated regions and water surfaces) and directly in the open mining areas a quite steep terrain and large radiometric differences.

The paper describes a test block in the brown coal open mining area of the company MIBRAG (Mitteldeutsche Braunkohlengesellschaft mbH) and discusses the results of aerial triangulation and digital DTM extraction with the software MATCH-AT and MATCH-T of INPHO GmbH Stuttgart.

2. CALIBRATION OF DIGITAL FRAME SENSORS

The use of digital frame sensors hardly differs in the application software from the use of scanned aerial photos. Advantages are above all the omission of the measurement of interior orientation. It is given by the calibration of the manufacturer and can be applied to all photos without any measurement. So far the procedure for calibration is non-uniform with respect to how the calibration is done and how these results are available to the users. Preferable are images corrected for distortion and principle point offsets. This simplifies the use of the digital sensors in different software substantially, since an ideal camera model can be applied.

Nevertheless still no uniform standards for certificates for the calibration of digital cameras are present. But efforts in this direction are already taken by EuroSDR and ASPRS (e.g. EuroSDR: http://www.ifp.uni stuttgart.de/eurosdr/index.html). Especially by using small format digital frame sensors an incomplete description of the calibration leads to difficulties or mistakes, since often it is not described, which model was used for the distortions (radial/tangential portions, sign of corrections etc.). Therefore it is preferable to deliver besides the photo and calibration data at least one photo with an internal and exterior orientation and some pixel coordinate measurements with corresponding ground coordinates. Thus it can simply be examined whether the mathematical model was correctly implemented (the projection of ground coordinates to the photo and the appropriate photo measurements must appear coincidently in a viewing tool) and if it is in accordance with a vendor's calibration.

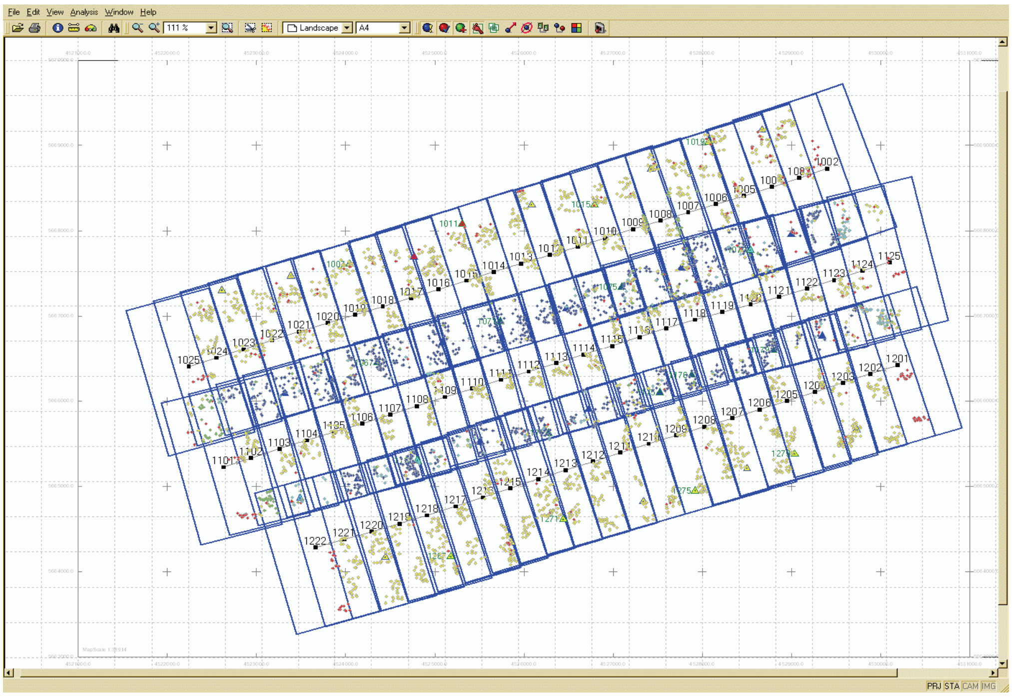

Figure 1: Image footprints of Test block with color-coded tie points

3. AERIAL TRIANGULATION WITH DIGITAL FRAME SENSORS

The digital aerial triangulation (DiAT) with digital frame cameras works by applying the same strategies as the DiAT with scanned aerial photographs. By the often smaller footprints of the photos in comparison to the scanned aerial photograph, the overlap's form and size reacts however more sensitively to changes of the orientation angles during the photo flight in strip direction and across. During more turbulent flight paths this can lead to much more irregular overlaps. A stabilized camera mount is often important if not even substantial condition for the photo flight. Any GPS/IMU observations can be utilized for better DiAT initialisation.

3.1. Coordinate System

A right-angled cartesian system is usually applied in the mathematical model of the block adjustment. Since however user coordinate systems (national coordinate systems) can only be approximated in small areas by a right-angled cartesian system with same scales in all coordinate directions, the associated inadequacies are often accepted and/or compensated with a simple model in block adjustment. With the introduction of observed orientations by GPS and IMU the choice of a suitable coordinate system gets however a higher significance (e.g. Greening 2000). Therefore INPHO will permit customers to use optionally a local cartesian topocentric coordinate system for the block adjustment computation. And it will provide the necessary tools to transform projects to different datums. More than 2000 different coordinate systems and their appropriate datum definitions are supported. Also the transformation of a project between different meridian zones is possible. The definition of coordinate systems follows OpenGIS Well Known Text descriptions of coordinate systems and is therefore easily upgradeable and compatible to GIS standards. (e.g. OGC Coordinate Transformation Services specification (01-009))

3.2. Measurement accuracy

Various block adjustments with digital fame sensors confirm the image coordinate measurement accuracy expressed by the a posteriori variance of unit weight (sigma naught) of about 0,1 – 0,2 pixel. Processing sensor data from cameras with a pixel size of 9 to 12 µm a final photo measurement accuracy of 1-2 µm is achieved. The potential of this high measuring accuracy leads to a much better description of remaining systematic errors. Additional selfcalibration parameters can be used to compensate for those errors, but new sets of parameters might be necessary especially for photographs from multi head sensors. Experiences have shown that additional parameters in the block adjustment are more frequently necessary (Alamús at al 2005 and Honkavaara et al). Remaining un-modelled systematic effects may lead to deformation of the block. Larger discrepancies in height (z) can be observed in those cases, less in planimetry (x,y).

4. DTM EXTRACTION WITH DIGITAL FRAME SENSORS

DTM generation with digital frame sensors differs likewise little from the use of scanned aerial photographs. For this test the product MATCH-T was used. The matching strategy has been changed for MATCH-T 4.0. from a model by model to a block oriented process. A processing of a block by individual models is not necessary any longer. Users can define and process one or more working areas in a block. With this strategy large areas or the complete block can be processed effectively, both for digital sensors and for scanned aerial photographs. As a result only one seamless DTM raster file for each working area is created, which can be divided into individual tiles if requested. The definition of working areas, visual inspection and editing in stereo can simply be performed with the new software **DTMaster.** No CAD software (MicroStation or AutoCad) is necessary to edit DTMs in stereo. Large data files with 10 million and more points are supported.

MATCH-T applies well known methods based on feature based matching along the epipolar lines of the overlapping photos, which can generate DTMs for large areas effectively. Although the algorithms are already known for more than 15 years, there are only few alternatives regarding the efficiency of the DTM extraction and the robust filtering. The large number of publications during the last years in the computer vision community shows the interest for new procedures for the 3D reconstruction. But despite the often impressing abilities of these algorithms to model details more complete and precisely, so far no alternatives are known to the author, in order to derive DTMs efficiently for large areas. Thus the procedures implemented in **MATCH-T** remains so far unrivalled concerning the efficiency in the DTM processing for large blocks of aerial photographs.

5. TEST BLOCK

MIBRAG (Mitteldeutsche Braunkohlengesellschaft mbH) made available the test block of a brown coal open cast mining area with image data coded in 8 and 12 bits. Table 1 shows the most important parameters and figure 1 shows the footprints of the photos with automatically extracted tie points.

Number of photos/strips	71/3
Flying height	1400 m
GSD	12 cm
Camera / digital Sensor	Intergraph/ZI DMC (fc. 120 mm ,7680 x 13824 pixel)
GPS/IMU	yes/yes
# of xyz check points	17
Area	Ca. 8 x 4 km
Radiometric resolution	12bit

Table 1: Parameters of test block.

The center of the block (figure 2) represents clearly the areas in that the coal mining takes place. Bright and very dark surfaces exist within a stereo model, which are also often weakly and very differently textured. The maximum differences in height in a model amount to about 120 m and are located in the area of the coal mine.

5.1. Aerial Triangulation with MATCH-AT

DiAT was processed for the 8 and 12 bit data. The larger quantity of image data resulted in a higher computing times for the 12 bit data. However the radiometric resolution has only a small influence on the number of multiple tie points, the accuracy of the results and the number of tie points. Table 2 shows a short summary.

	8 bit data	**12 bit data**
Number of extracted points	15248	15466
Sigma naught of adjustment in µm without/with selfcalibration	2,0/1,6	1,9/1,5
RMS at check points x/y/z in cm in ‰ of flying height	5,4 /4,8 / 7,3 0,04/0,03/0,05	5,7 /4,8 / 7,2 0,04/0,03/0,05
3 fold points/ 4 and more fold points	2204/1403	2323 / 1394
Processing time per image in sec. (P4-2,8GHz, 512KB L2 cache)	17	21

Table 2: Results of AT with MATCH-AT

The obtained empirical accuracy on check points corresponds to the results of Honkavaara et al, computed during an investigation of a Vexcel/UltraCamD camera. The application of selfcalibration parameters was necessary, alternatively the RMS on check points is worse by a factor of 2.

5.2. DTM Extraction with MATCH-T

For the MATCH-T computation the complete block was processed in separate runs for the 8 bit and 12 bit data. A DTM grid size of 3m was selected. Table 3 summarizes the results for the 12 bit data. In relation to the 8 bit data MATCH-T extracted on the average about 11 % more points. If one analyses the change of the number of points per model area, then the number increased from minimum 5 to maximally 23 % (see Figure 4). Related to the total area of approx. 32 km² MATCH-T measures in this block on the average 16 points/m². A robust filter reduces the large number of **504 million 3D points** to a raster DTM. It becomes easily clear that even in this small sized block the data size increases so fast that a reduction to a raster is necessary for further processing.

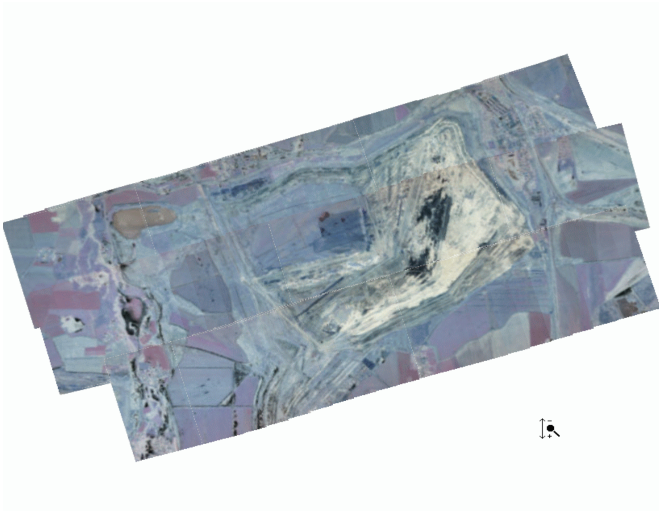

Figure 2: All photos projected onto a fixed height plane

The DTM file with a 3 m by 3 m grid consists of approx. 5 million points for the 71 photos of the test block. For the creation of the grid on average **70 points per raster mesh** where used. Due to the high point density a computation of a 1 m by 1 m raster would be even reliably possible in this case.

During the matching the correlation coefficient of the 12 bit data is on the average around 1 % better compare to the 8 bit data. That appears small, but related to the possible range of the correlations from approx. 0,9 up to the ideal value 1,0 it is still a considerable increase.

	8 bit	**12 bit**
Number of matched 3D points	455 million	504 million
Number of DTM grid points per model area in 68 model areas from /to	4,8 – 8,8 million	5,3 – 9,6 million
Mean correlation coefficient Mean correlation coefficient in 68 model areas (min. / max.)	0,92 (0,90 /0,94)	0,93 (0,90 /0,95)

Table 3: Results of MATCH-T for test block

The matching performance on a standard PC (P4, 2,8 GHz, 512 KB L2 cache) was 11.600 points per second, resp. about 10 minutes per model area. The processing time of all pyramid levels is considered in this number.

Visual control of the raster with the help of the stereo viewer in **DTMaster** shows a very good representation of the terrain by the final DTM grid. Even steepest edges are very well described. Figure 3 shows a 3D view of one profile presented by raster points (extension: 350m x 900 m). An analysis of the differences of the extracted DTM and a comparison with individual check measurements was not performed in this test up to now.

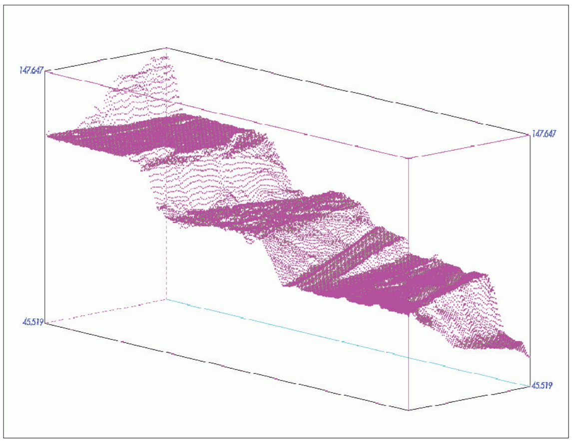

Figure 3: profile view of DTM area

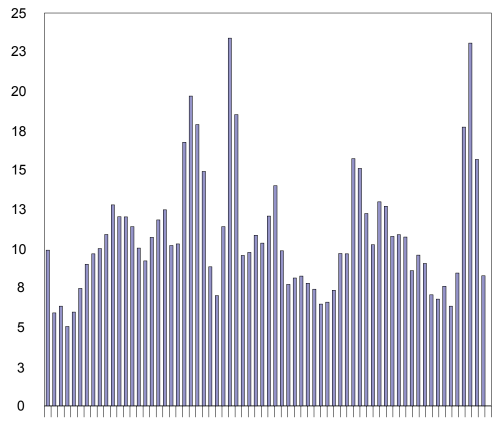

Figure 4: increase of number of 3D points in percent between 8bit and 12 bit data for 68 different model areas

6. SUMMARY AND CONCLUSIONS

Digital sensors will continue to be used in aerial photogrammetry simply because of their ability to provide aerial photos with excellent radiometric quality. The use of the 12 bit in relation to 8 bit data in the matching has a rather small influence in the DiAT with MATCH-AT. The matching strategy is able to switch to other matching areas, if this is necessary due to bad textures. Whether higher radiometric resolution has an positive impact to photos covered with large areas of bad texture (e.g. desert areas) could not be examined with this test. An improvement is to be expected however. Contrary to the experience in MATCH-AT, the higher radiometric resolution of 12 bits offers a positive influence in MATCH-T. The higher point density leads to a larger redundancy during the filtering of the 3D points and thus to a more reliable DTM generation.
In this test no manual measurements were used to draw further comparison. The comparison is limited here only to general characteristics. Further analyses of the data and results, e.g. the analysis in which areas higher radiometric resolution particularly improves the DTM must still be made, also whether any application of adaptive procedures affects and improves the final product.
To use the entire geometrical potential of the digital frame sensors a complete calibration is required. Since it is not to be expected that all camera manufacturers agree on only one procedure of the calibration and on a uniform certificate in the near future, the application software has to support different calibrations. The utilisation of pre-corrected data (corrected for radial, tangential distortion, principle point, radiometric adjustment etc.) simplifies the work and the camera manufacturers already supports this approach. Besides however, investigations (Alamús et al 2005)

show that the numeric evaluation of the remaining residuals after the block adjustment gives also reasons to an additional refinements in the sensor model.
A further sensor independent refinement of the camera model in the application software can be implemented via correction grids. These grids can be determined for example by self calibration parameters in the block adjustment or by import functions from a camera vendor's calibration. A simple grid can be used as look-up table to apply a refined camera model. The exchange of an improved camera model or a new calibration between different parts of the user software is simply possible . Since users more frequently experiment with small format consumer cameras, INPHO will support the grid approach in order to support any frame camera model. Not every digital consumer camera is suitable for photogrammetric tasks. The proof of a stable calibration is crucial thereby for a successful application.
The high matching speed of 8.000 to 12.000 points per second inside MATCH-T for the DTM generation shows nicely the large potential of digital photogrammetric processing. With the rapid development of the hardware one will reach a 3D point measuring speed on a single workstation, which is close to those of today's laser scanners. By appropriate parallel and/or distributed processing of the DTM extraction this could be achieved already with today's technology.

7. REFERENCES

Alamús R., Kornus W., Palà V., Pérez F., Arbiol R., Bonet R., Costa J., Hernández J., Marimon J., Ortiz M.A. , Palma E., Pla M.,Racero S. ,Talaya J. (2005): Validation Process of the ICC Digital Camera. ISPRS workshop High-Resolution Earth Imaging for Geospatial Information, Hannover 2005

Cramer M. (2005) Digital Airborne Cameras- Status and Future . ISPRS workshop High-Resolution Earth Imaging for Geospatial Information, Hannover 2005

Coordinate Transformation Services (CT) specification (01-009) http://www.opengeospatial.org/docs/01-009.pdf

Fricker P., and Rohrbach A.(2005): Pushbroom Scanners Provide Highest Resolution Earth Imaging Information in Multispectral Bands. ISPRS workshop High-Resolution Earth Imaging for Geospatial Information, Hannover 2005

Greening W.J. T., Schickler W. and Thorpe A. J.(2000), The Proper Use of Directly Observed Orientation Data: Aerial Triangulation Is Not Obsolete, 2000 ASPRS Annual Conference, Washington, DC, May 22-26, 2000

Honkavaara E., Markelin L., Ilves R., Savolainen P., Vilhomaa J., Ahokas E., Jaakkola J., Kaartinen H. (2005). In-Flight Performance Evaluation of Digital Photogrammetric Sensors. ISPRS workshop High-Resolution Earth Imaging for Geospatial Information, Hannover 2005

Mostafa, M.M.R. (2003): Design and Performance of the DSS, Fritsch (ed.) Photogrammetric Week 2003, Wichmann Verlag, pp. 77-87

Sigle M., Heuchel T., (2001): MATCH-AT: Recent Developments and Performance Photogrammetric Week 2001, Wichmann Verlag

ACKNOWLEDGEMENTS

We would like to express our acknowledgements to the company MIBRAG (Mitteldeutsche Braunkohlengesellschaft mbH) for providing us with the DMC image data and the helpful discussions with Mr. Frank Reetz from MIBRAG.