GEOMETRIC CALIBRATION OF THE DMC: METHOD AND RESULTS

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ABSTRACT:

The Digital Mapping Camera (DMC) is the well-known new digital aerial camera system of Z/I Imaging, an Intergraph - Carl Zeiss joint venture. Analogue aerial cameras manufactured by Carl Zeiss have been successfully used around the world for many decades due to their outstanding photogrammetric performance. The DMC will continue this success and uses therefore an optical design based on CCD-matrix sensors to achieve high geometrical resolution and accuracy together with multi-spectral capabilities. It comprises 8 synchronously operating CCD cameras. Four parallel cameras can generate multi-spectral imagery for the acquisition of colour composites. Four panchromatic images from converging cameras are mosaicked digitally to form a single high resolution image with a large ground coverage. The paper describes this key post processing mosaiking procedure to transform the four individual high-resolution panchromatic images into one virtual image which can be considered being of a normal perspective projection, usable by all existing exploitation systems. Additionally, results of the geometric calibration and a test with DMC flight data are presented.
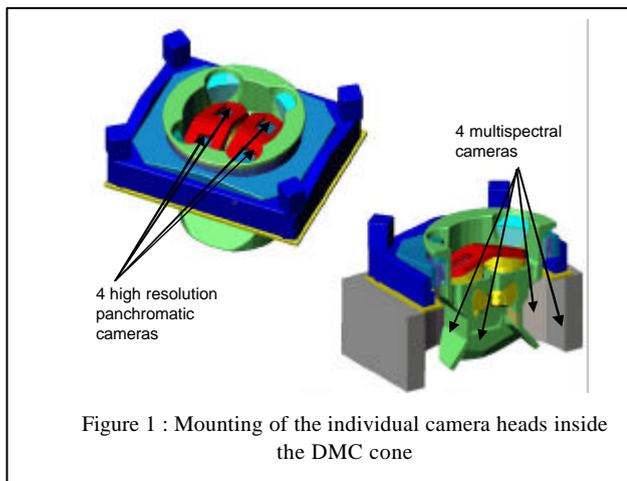
1. INTRODUCTION

The Digital Mapping Camera (DMC) is based on array CCD's (Theuwissen, 1995). Ideally, a single chip with an appropriate size and resolution should be used to transfer the photogrammetric capabilities of the analogue film cameras like the RMK-Top to the digital technique. However, such a large-format chip is not available yet for technological and economical reasons. Since a large field of view is mandatory in aerial photogrammetry due to the high accuracy requirements and by economical reasons, several CCD's can be combined to deliver the large ground coverage.

The general principle, design issues, comparisons, technical details and the development stages have been published in many papers, e.g. Hinz (1999), Tang et al. (2000), Heier et al. (2002). This paper focuses therefore on the mosaicking process of the images acquired by the four panchromatic camera heads. Details of the computation techniques are given and results of the investigation into possible error sources are shown. The generated virtual images of a test flight in February 2002 have been used to proof on the one hand the methods, algorithm and

accuracy of the post processing and to evaluate the photogrammetric potential of the acquired imagery on the other hand.

Figure 1 : Mounting of the individual camera heads inside the DMC cone

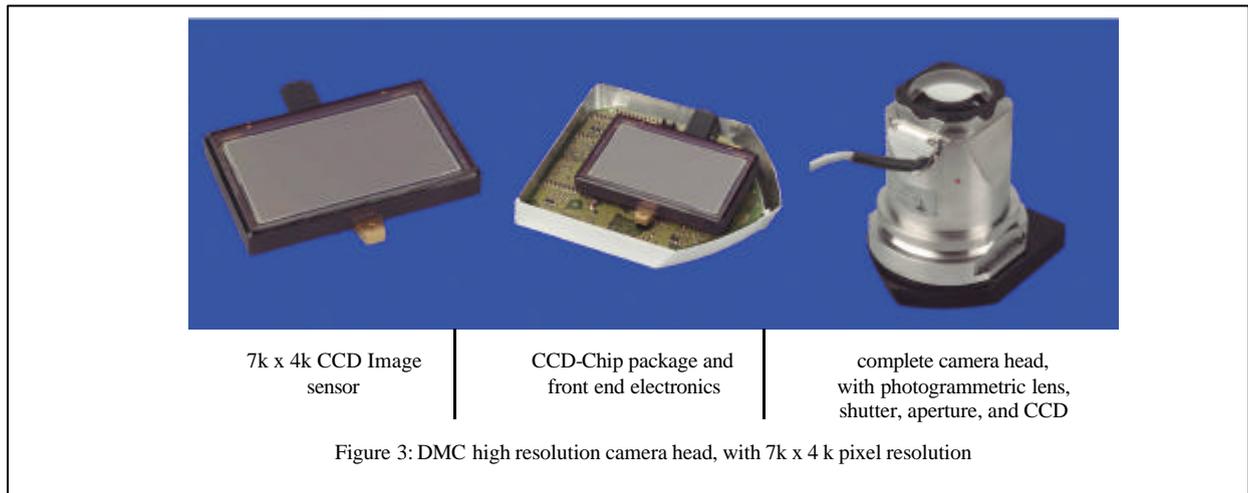Figure 2: View from below in an aircraft

The DMC contains four panchromatic and four multispectral camera heads. The panchromatic heads are looking downwards in a slightly tilted position to ensure a maximum of ground coverage (Fig. 1). A view from below to the mounted DMC inside an aircraft is given in Fig. 2. The mounting of the panchromatic camera heads (Fig. 3) is modelled by four sets of six exterior orientation parameters, three positions xyz of projections centers and three orientation angles $\omega\varphi\kappa$ for the tilting of the heads inside the DMC cone. The positions xyz of the panchromatic camera projection centers within the DMC cone are precisely known, while the

exact mounting angles of the four heads are not available with the required accuracy. Precise determination of the angles is absolutely necessary, otherwise it's not possible to merge the resulting individual images into one large high-resolution virtual image seamlessly. The determination of the mounting angles is therefore essential for the performance of the DMC and is called 'platform calibration'. Please note that these four sets of exterior orientation parameters only model the mounting of the camera heads inside the DMC cone, they do **not** describe the position and rotation of the DMC with respect to the ground coordinate system. This is done conventionally by one different set of six exterior orientation parameters for the virtual image.

2. DMC PROCESSING OVERVIEW

From acquiring the raw imagery up to the final high-resolution RGB image, several procedures and calibration steps are necessary. At first, for each of the 8 camera heads, the geometric and radiometric calibration is determined in the laboratory. This step is also known as 'geometric and radiometric calibration of a single camera head' and done once during manufacturing the DMC. The information generated during this procedure will then be used by the post processing software to mosaic the high resolution images and the colour channel images into one high resolution RGB virtual image. The post processing software is performing the following tasks for every image exposure:

- Extraction of tie points in the overlapping areas of the four panchromatic images using matching techniques. The laboratory calibrations of the single camera heads are applied to generate corrected image coordinates of the tie points.
- Determination of the mounting angles of the panchromatic heads by a bundle block adjustment technique (= "platform calibration")

| 7k x 4k CCD Image sensor | CCD-Chip package and front end electronics | complete camera head, with photogrammetric lens, shutter, aperture, and CCD |

Figure 3: DMC high resolution camera head, with 7k x 4 k pixel resolution

- Computation of transformation parameters using the four sets of exterior orientation parameters to map from the single images to the virtual image.
- Projection of the single panchromatic images to the high resolution virtual image using the computed transformation parameters.
- Extraction of tie points between the high resolution virtual image and the four colour channel images.
- Computation of transformation parameters using the extracted tie point image coordinates to map from the colour channel images to the virtual image.
- Mapping of the colour channel images to the virtual image using the computed transformation parameters (Colour fusion).

- Generation of overviews of the high resolution colour image and writing the output to disk.

3. PLATFORM CALIBRATION

The following data serves as input for the platform calibration:
- four panchromatic images
- lens distortion information for the four panchromatic images
- precise knowledge of the position of the panchromatic camera projection centers within the DMC cone
- approximations of the orientation angles (tilting of the camera heads)
  - approximations of the focal lengths of the panchromatic camera heads
  - flying height above ground

In the first step, tie points in the four overlapping regions are extracted. This is done by mapping a point grid from a master image via the approximated orientation parameters to all three slave images. The resulting matching candidates will then be refined by least squares matching techniques. The tie

Figure 4: Extracted tie points in the four panchromatic images
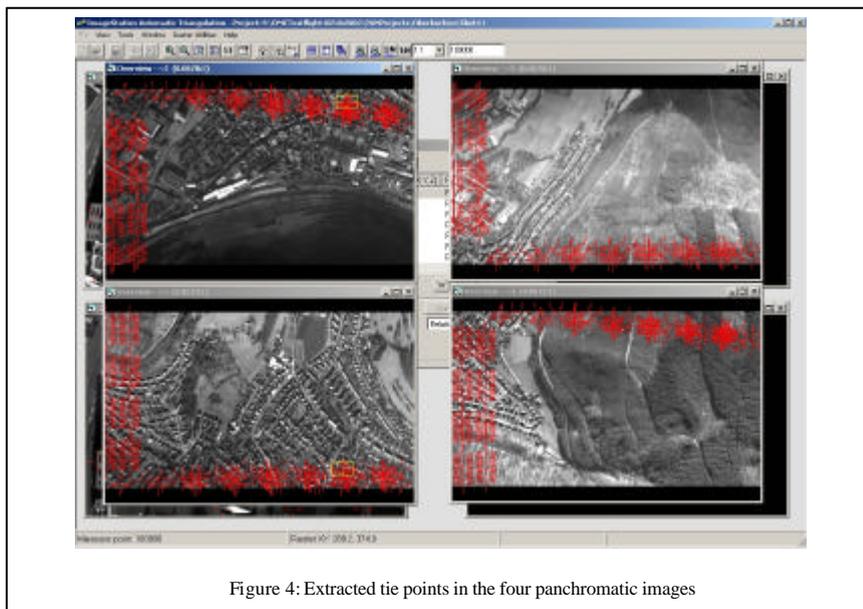
point image coordinates are corrected for lens distortion and serve as main input to the bundle block adjustment module. An example of extracted tie points is shown in Fig. 4, the total number of tie points can be selected and optimised for computation speed. However, investigations show that very good results can be already achieved by using only 30-50 well distributed points.

The next step in performing the platform calibration is the bundle block adjustment module. This module is based on the well known software package BLUH (Jacobsen 1998). It solves for the four sets of orientation angles and for three focal lengths. Unknowns of the common bundle adjustment of the four panchromatic images are attitude data for three images in relation to a reference image, 3 focal length and a special additional parameter controlling the projection centre offset in relation to the flying height above ground, while the location of the precisely known projection centers are used for the determination of the other unknowns.

4. RESULTS

The platform calibration described above was successfully tested with imagery acquired during a DMC test flight at Feb. 16, 2002. A total of about 350 complete images was taken from different flying heights, including several specially designed calibration sequences and a regular photogrammetric block. Thus the CCD chips were bonding samples, the radiometric and internal geometric quality of the images is excellent as shown below. For each image shot, an individual bundle block adjustment for platform calibration purposes is performed. As usual in photogrammetry adjustment techniques, a sigma naught is computed as a quality indicator. This sigma naught in combination with the maximum residual of the adjusted image coordinates for the Feb. 16- test flight is shown in Fig. 5. The mean values of the sigma naught of the adjustment are about 1 micron, which is a twelfth of the pixel size of 12 microns. The maximum residual in image coordinates does mainly not exceed 6 microns, which is half of a pixel. These values clearly indicate the quality of the internal DMC accuracy and the bundle block adjustment orientation mechanism.
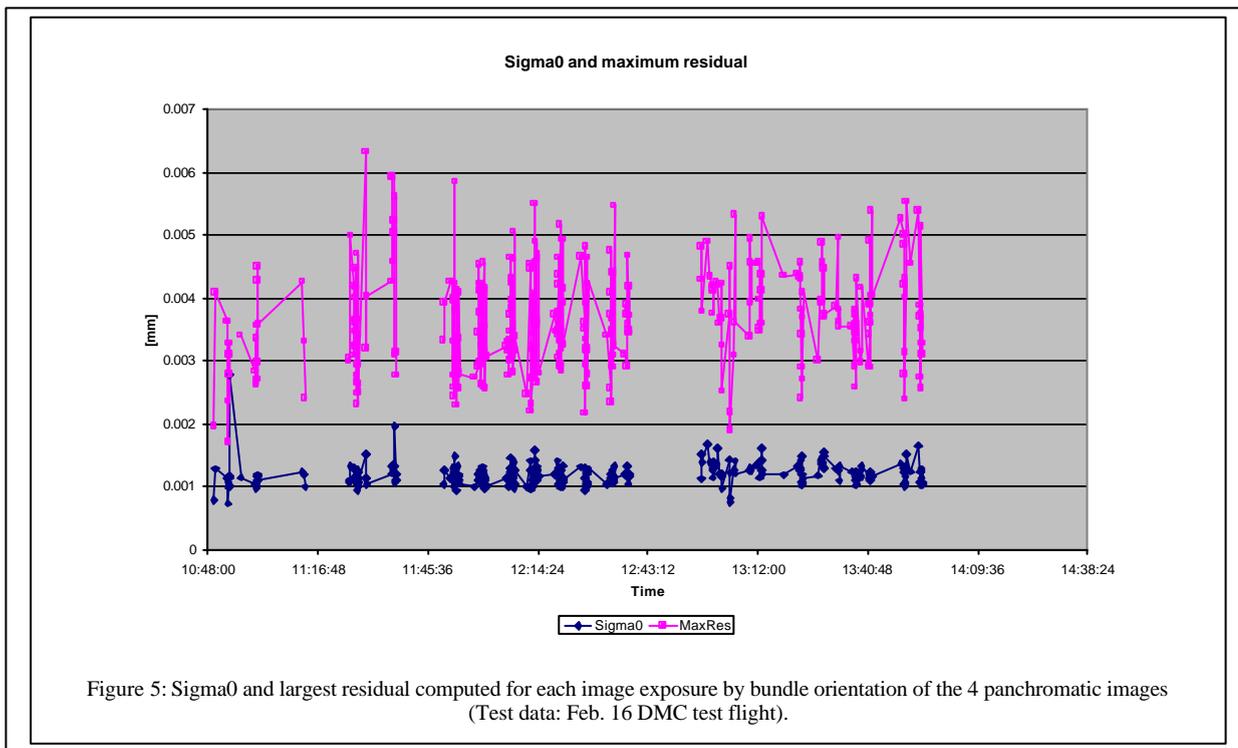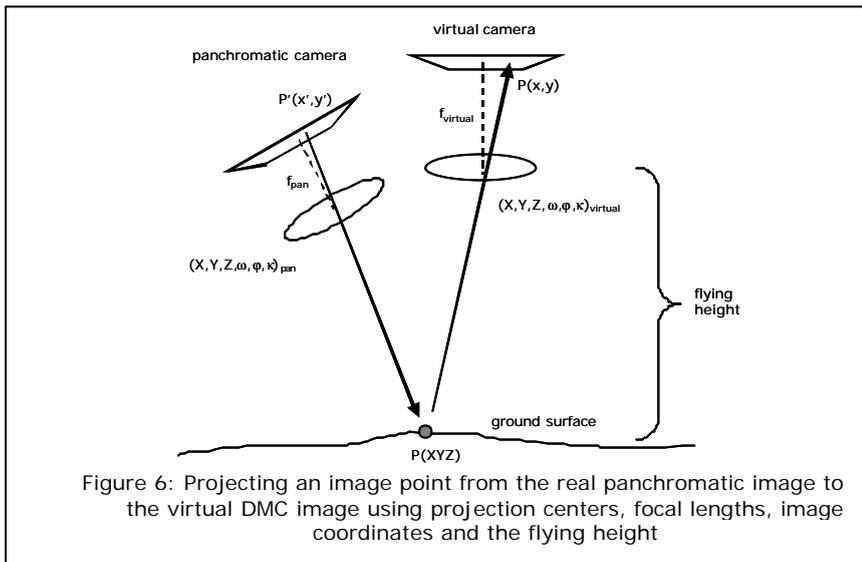

Figure 5: Sigma0 and largest residual computed for each image exposure by bundle orientation of the 4 panchromatic images (Test data: Feb. 16 DMC test flight).

5. MOSAIKING PROCESS

Figure 6: Projecting an image point from the real panchromatic image to the virtual DMC image using projection centers, focal lengths, image coordinates and the flying height

The mosaicking process takes the results of the platform calibration and combines the four panchromatic images into the virtual DMC image. The position of the projection centers of the panchromatic cameras is well known, the tilting angles as well as the focal lengths of the cameras are adjusted by the platform calibration. To project each pixel from the panchromatic camera to the virtual DMC image, it's necessary to define the properties of the virtual camera. The virtual projection center is per definition located in the center of the four real projection centers, the optical axis of the virtual camera is defined as the mean optical axis of the four panchromatic optical axes. The focal length can be selected as desired, but was set to 120 mm for minimisation of scale differences. All this information allows the projection of each position in the real image to the virtual image using the well-known colinearity equations (Fig. 6). For performance reasons, the method of projection described above is only applied to raster points forming a grid on the panchromatic single images. These grid points are transferred rigorously (including lens distortion information), and the resulting image coordinates gives together with the input values four sets of identical points, one for each panchromatic image. Following by this, four sets of rational function coefficients are fitted to the identical points using least squares techniques. If the desired level of accuracy is not reached, more grid points are generated, until the
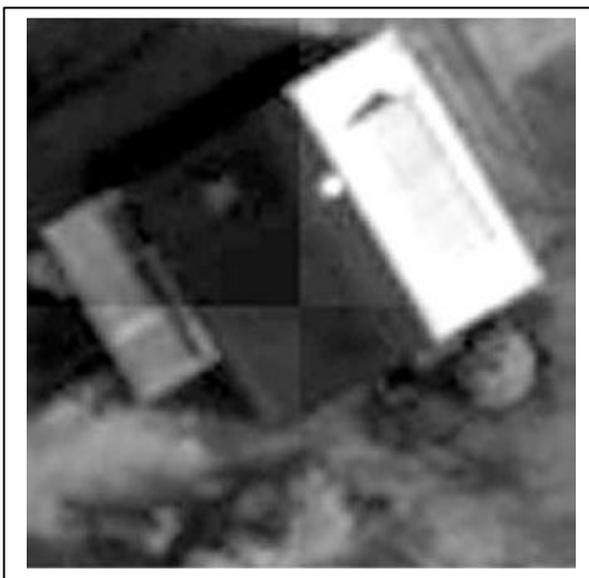

Figure 7: Results of the mosaiking process: The center of the virtual DMC image is located in the center of the roof. The tie point extraction, the lens distortion correction and the rectification has been done. The four edges of the panchromatic images fit together very well as it can be seen in the left image. After applying a blending algorithm, even the radiometric differences between the images are removed (right image).

maximum residual is less than a certain threshold. By using the rational function coefficients, a performance optimised software maps the single images directly into the virtual image tile by tile. During this mapping, a blending algorithm ensures a smooth transition between the four images in the virtual DMC image (Fig. 7).
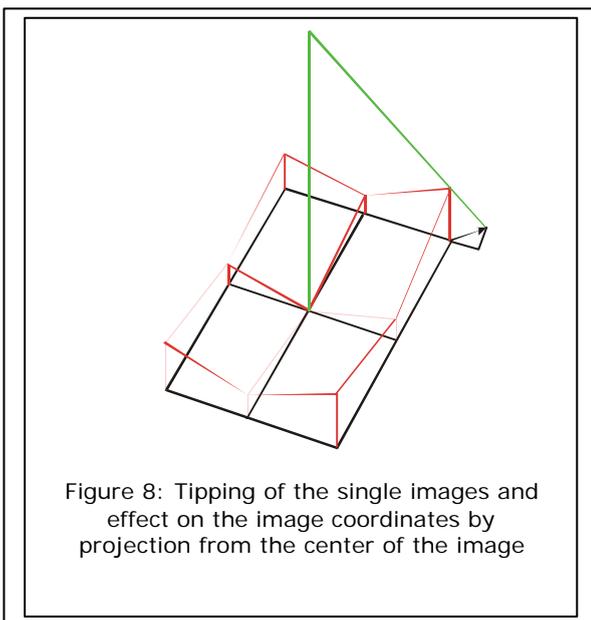
6. ERROR SOURCES

Several investigations have been performed to check the accuracy and results of the platform calibration and the mosaicking process with respect to possible error sources.

6. 1 Flying Height error

The most common error may be a not correct flying height used during the mosaicking step, which leads to a small displacement of the single images to the center or to the edge of the virtual image. By combining the images with bundle block adjustment, this effect is compensated by the orientation angles, and therefore a tipping of the single images against the virtual image can be observed. This effect can be compensated by an additional parameter:

$$Dx = (0,9 \bullet ABS(x') + 1,1 \bullet ABS(y')) \bullet x'$$

$$Dy = (0,9 \bullet ABS(x') + 1,1 \bullet ABS(y')) \bullet y'$$

Figure 8: Tipping of the single images and effect on the image coordinates by projection from the center of the image

The factors 0.9 and 1.1 are caused by the different extent of the virtual image in column- and row direction. For verification purposes several images with a flying height of 150 m (instead of 1500 m in the correct case) have been mosaicked. The bundle adjustment with the additional parameter determined this one significantly.
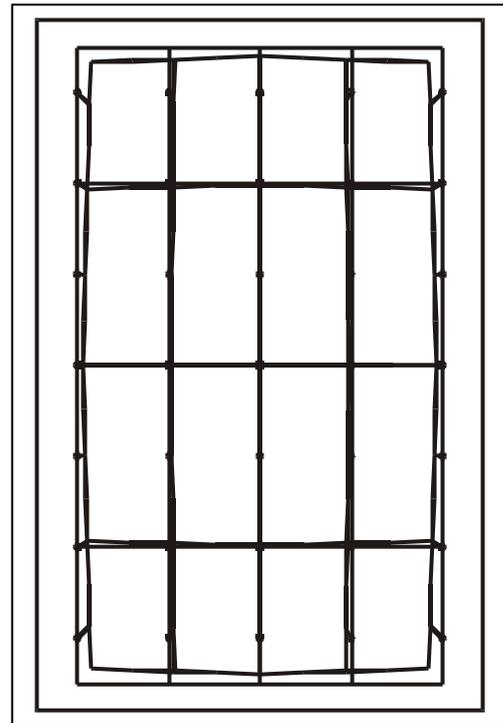

Figure 9: Effect of wrong flying height to the mosaicked image, modelled by parameter #29

6.2 Influence of TDI shift

The time delayed integration (TDI) shift is comparable to the forward motion compensation (FMC) used by analogue film cameras. The TDI mechanism allows the shift of the image in the focal plane dependent from the flying height and the aircraft speed. Under special conditions (e.g. very long exposure times), this shift can be about several dozens of pixels. An empirical investigation checked the influence of the TDI shift to the geometry of the virtual DMC mosaicked image:

1. Setting up a grid of 19x19 points in an single panchromatic image

2. Shifting of the points (1.) by 2.4 mm (200 pixels) in y-direction (e.g. to TDI-shift)
3. Transformation of the grid points (1.) into the virtual mosaicked image using mean values of orientation angles (φ = 20.05 grads, ω = 11.13 grads, κ = 96.78 grads)
4. Perspective transformation of the shifted points (2.) to the rotated points (3.). The perspective transformation is geometrically equal to the transformation from single image to the virtual image.

The differences between the transformed shifted points and the rotated original image points describes the deformation caused by a TDI-shift of 200 pixels. Only rounding errors were observed, the maximum difference is 1 micron, the quadratic mean values are computed as 0.0. This clearly indicates that a shifting of the image points due to the TDI mechanism has absolutely no effect to the mosaicked virtual DMC image, it's fully compensated by the adjusted orientation angles.

6.3 Non-square form of the pixels

It is assumed that the pixels on the CCD chips are square arrays with a side length of 12 microns. However, a bundle block adjustment of a block with high precision ground control points and mosaicked virtual images revealed that when a self calibration with additional parameter is enabled, the affine parameter is significantly determined. Since the virtual camera is per se error free, the observed affinity seems to be caused by a non-square form of the pixels. The computed affine parameter has a value of about – 1.11E-4 ± 2.79E-6, which results in a 11.9987 x 12.0013 microns pixel size in column- and row direction, respectively. This order of magnitude (1.3 nanometer) is for sure less than the accuracy of the CCD manufacturing process. This correction can be applied to the post processing steps.

7. ACCURACY ASPECTS

To proof the performance and the optical accuracy of the camera, a test area around the airport Elchingen ins South/West-Germany was installed. A total of 21 full ground control points were measured via GPS and simultaneously adjusted. Therefore their standard deviation in X, Y and Z is not exceeding 10 mm. These ground control points were manually measured in 8 mosaicked virtual DMC images from 2 crossing strips (Fig. 10) acquired during the Feb. 16 test flight. The flying height above ground was 1544 m and the image scale was 1 : 12 870. This gives a ground pixel size of about 15 by 15 cm. The bundle block adjustment computed a sigma naught value of s = 1.7 µm (0.14 pixel), which is equal to 2.2 cm on the ground. Later automatically extracted tie points were added to the data set described previously, and the bundle adjustment came out with a sigma naught of s = 1.6 µm corresponding to 0.13 pixel or 2.1 cm on the ground. A self calibration by additional parameters have been applied for verification purposes, but all parameters were removed due to no significance. A bundle block adjustment with only some of the control points was leading to mean square differences at the independent check points of 3.6cm for X and Y corresponding to 0.23 pixel and 6.0cm for Z (0.39 pixel). This proofed the excellent geometric quality of the mosaicked virtual DMC images.
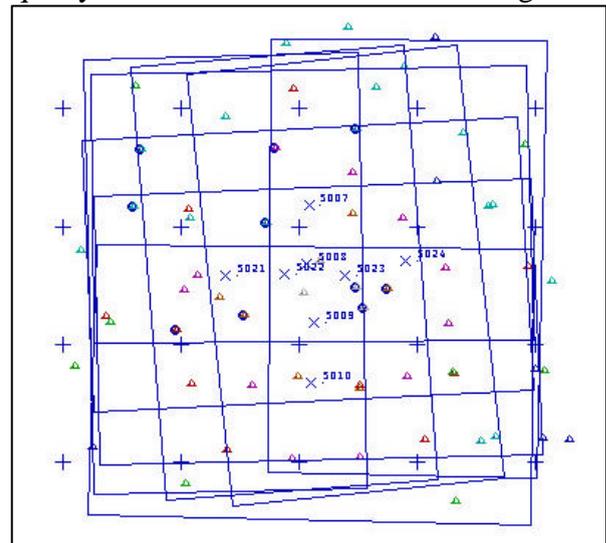

Figure 10: Footprints (Image positions and ground control points) of the airport Elchingen area

Using the derived image orientations, a digital terrain model (DTM) of the Elchingen area was

computed. A comparison with a DTM measured in the field gives a mean accuracy of the DMC-derived DTM of about 10 cm.
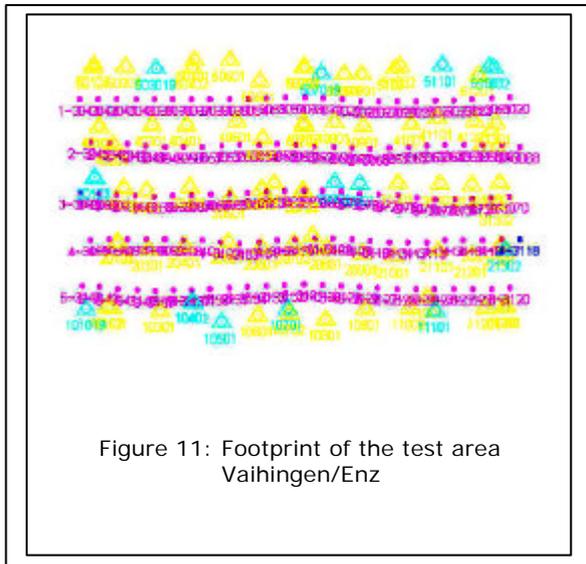

Figure 11: Footprint of the test area Vaihingen/Enz

Another test on a different test area was performed using the Vaihingen/Enz ground control network of the University of Stuttgart. These block (Fig. 11) consists of 120 mosaicked DMC images in 5 strips, the flying height was 1210 m and the image scale was 1:8000. The pixel size on the ground was 9.6 cm and 16 full ground control points were available. After automatic aerotriangulation, the bundle block adjustment computed a sigma naught value of s = 2.4 µm corresponding to 0.2 pixel or 1.9 cm on the ground.

CONCLUSION AND OUTLOOK

An overview about the post processing steps of the DMC is given. The developed method to combine the four individual panchromatic images into one virtual one was successfully tested with flight data. The achieved accuracy is in the range of 1 micron for the mosaicking process, and the actual remapping of the four images into one virtual generates therefore absolutely seamless mosaicked images. Possible error sources during the rectification procedure have been investigated but nothing was detected. Final tests with the mosaicked images of a test flight gave excellent

photogrammetric results, the achieved sigma naught values are in the order of about 0.16 pixel. At independent check points the accuracy in X and Y is in the range of 0.23 pixel and for Z 0.4 pixel. More test flights with the digital camera DMC will be performed to check these first results, but it seems that the digital camera exceeds the geometric quality of an analogue film camera.

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