Calibration of the Digital Modular Camera

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ABSTRACT

At this moment, airborne digital cameras based on different technical concepts are under development. In view of the high geometric accuracy requirements in photogrammetry, Z/I-Imaging focused its design and development of the DMC on a matrix-based CCD sensor. The DMC uses a modular design to achieve high geometrical resolution together with multispectral capabilities. It comprises eight synchronously operating CCD-array cameras. Four parallel cameras can generate multi-spectral R,G,B and Near Infrared imagery for the acquisition of color composites. Four panchromatic images from converging cameras, are mosaicked digitally to form a single high resolution image. The quality and accuracy of this composed virtual image is based on the validity of the DMC platform calibration. The paper will describe the post-processing steps of DMC image data to generate virtual central perspective images. Additionally, this paper will give an overview of the entire DMC calibration as the basis to integrate DMC imagery into existing photogrammetric workstations. Finally, it discusses the potential of digital imagery based on first DMC flight results.

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1. INTRODUCTION

Carl Zeiss presented its first aerial photogrammetric sensor, which was a handheld balloon camera, nearly 100 years ago. Since then aerial mapping cameras like the RMK products have been used for decades and established a high performance standard in aerial photography. In recent years, airborne cameras have evolved into complex system solutions. Besides improvements of the camera technology itself extensive compensation of aircraft motions, photoflight management with GPS navigation, and the use of Inertial Measurement Units (IMU) for the precise determination of the exterior orientation have been incorporated. Film-based aerial cameras using long rolls of nine inch wide film for image acquisition and image storage are still being used in a wide field of applications. The capacity of a single roll of film goes up to 500 high resolution color images while the frame rate for a complete exposure cycle is less than two seconds.

Film-based aerial camera systems are mostly used for mapping applications with photo scales between 1:5,000 and 1:15,000. For this photogrammetric application they have to fulfill high accuracy and resolution requirements. Z/I Imaging, will continue the Carl Zeiss tradition in the field of film-based aerial camera systems with the forthcoming market introduction of its new Digital Modular Camera DMC (figure 1).

The DMC concept was presented for the first time in fall 1999 [Hinz, 1999], [Heier, 1999]. Various details were presented parallel to the development progress [Hinz, 2000], Diener, 2000], [Tang, 2000]. The multi-camera module approach of the DMC allows the combination of high panchromatic resolution with multi-spectral capability. It is the goal of the DMC to reach this outstanding performance of today’s film-based cameras.

Figure 1: ***DMC*** Camera Unit in gyro-stabilized mount

2. Z/I-IMAGINGS DIGITAL MODULAR CAMERA DMC

To achieve utmost photo flight efficiency, it is essential to cover a wide terrain area with one single flight line. Today’s film based aerial cameras have set a standard with 153mm wide angle lenses. Together with the nine inch film format used, this results in a ground coverage of 74°. At the same time, the demands on the photo quality are very high. In addition to good resolution, it is above all the geometric accuracy which is of decisive importance for photogrammetric applications. As the size of commercial available image sensors is limited, it is not possible to choose the ideal solution for the focal plane of an airborne digital camera to fulfil these photogrammetric requirements. This ideal solution would be one individual, large-area CCD chip in the size of a silicon pizza, similar to existing film formats. The DMC overcomes this limitation by parallel operation of several compact camera heads (figure 2).

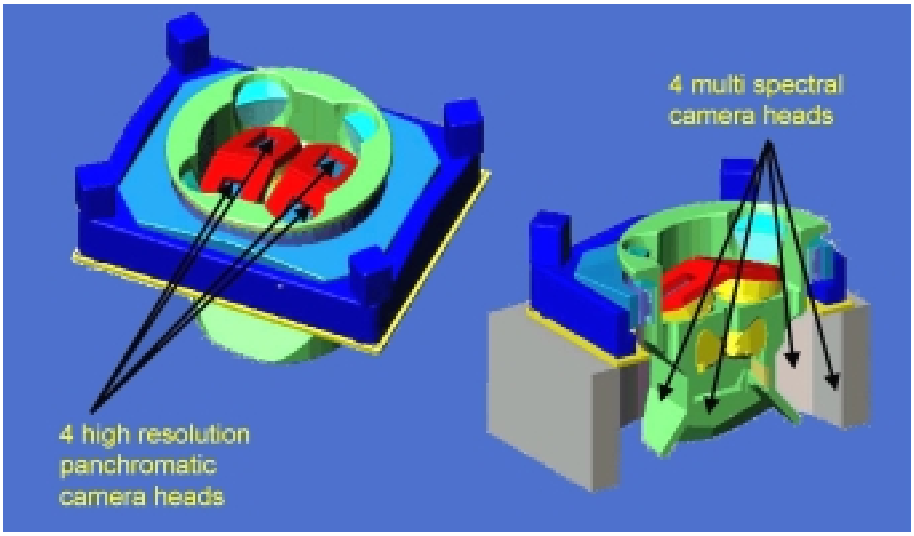

Figure 2 : Optical concept of eight head ***DMC*** configuration

3. OPTICAL CONCEPT DMC

The centerpiece of the system is the camera head and the CCD matrix sensor as the key element. However, for the image recording procedure it is important to have a ground coverage with one shot as wide as possible. This is provided by parallel operation of several compact camera heads, where each CCD has its own lens. The modules are directed to the scene at slightly displaced field angles. Figure 3 gives an overview on this optical concept within the photoflight application.

The DMC is equipped with four 7k x 4k large area chips and f/4 high performance lenses with a focal length of 120 mm in the panchromatic channel. Special care has been taken to assure homogenous and flat response of the MTF (Modulation Transfer Function) over the entire image field of the lenses. Figure 2 shows the arrangement of the four panchromatic channels in the optics frame. The resulting resolution of the system on ground is > 13,000 pixels across track and approx. 8,000 pixels along track. The resulting cross track coverage angle for the panchromatic system is 74°.

The color channels are mounted on the outer rim of the optics frame. This allows the collection of images for instance in the Red, Green, Blue and a separate infrared channel for taking simultaneous true and false color images at the same time. In order to achieve high quality color separation, each color channel features a separate lens, a CCD-chip and a high performance color filter, based on non-organic material. The color channels have reduced ground resolution compared to the panchromatic channel and the lenses are looking down in central perspective view. A high performance wide angle lens with high opening f/4 and f=25 mm is combined with a 3k x 2k CCD chip.

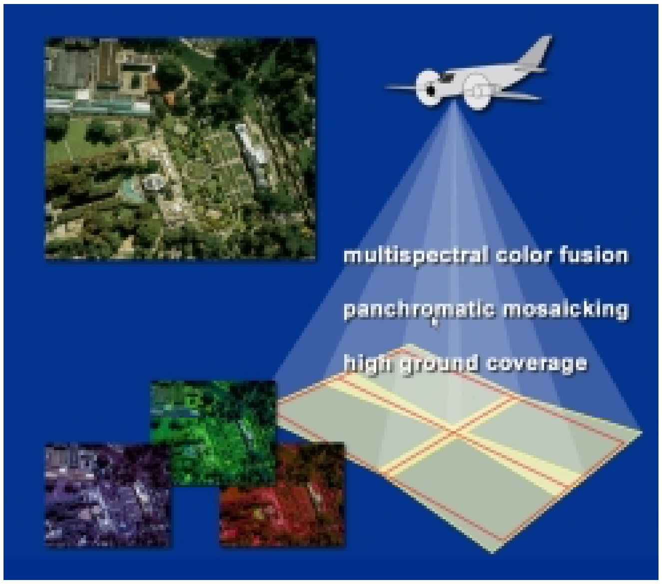

Figure 3 : Optical concept of eight head ***DMC*** configuration

The idea to enlarge the field of view by combining several lens systems is well known since the early days of aerial photography. Several aerial cameras with two, four, seven and even nine lenses were built [Szangolies, 1986], [Talley, 1938]. Complicated special rectifiers and plotting instruments were developed to restore the image geometry. Handling of this image evaluation instruments was troublesome and the use of multi-lens cameras came to an end during the late 1940's after camera manufactures like Zeiss had developed new single-lens cameras with larger negative format. Today, the image restoration of such a multi-lens camera can be done within digital imagery completely by software. The quality and accuracy of the final resampled virtual DMC image is based on the validity of the complete set of calibration data.

4. CALIBRATION OVERVIEW

To achieve high quality imagery, the DMC system is calibrated at the manufacturer site. The calibration is done in two steps. First, the single camera heads are calibrated. Secondly, after having assembled the multi-head configuration, a platform calibration is performed. The single head calibration considers radiometric and geometric influences for each camera. The calibration values are stored with each camera head and will be corrected during the image post processing step. The relation of single sensors with respect to an internally defined platform system, represents the platform calibration. The platform calibration consists of the spatial positions of each sensor related to the platform reference and if necessary of radiometric corrections to adjust the different CCD arrays.

5. CALIBRATION OF A SINGLE CAMERA HEAD

Each single camera head of the DMC is calibrated with regard to geometry and radiometry. The geometric calibration can be seen as the interior orientation of the classic film based camera (like RMK TOP). The radiometric calibration is done to correct single defects of the CCD sensors and for compensating the different sensitivities of single pixel elements. Also the influences of the operating environment are equalized by the radiometric correction of the taken images.

5.1 Camera Head Geometric Calibration

The following description gives a comprehensive overview about the geometric calibration of one single camera head. The two main parts are explaining the theoretical model of the camera and the calibration process itself.

5.1.1 Geometric Calibration Model

For the calibration of the DMC camera heads the Australis 10 parameter model [Fraser, 1997] is used. The following formula (5.1) describes the whole correction of the image coordinates :

$$\begin{aligned}\Delta x &= \Delta x_0 - \frac{\bar{x}}{\bar{z}}\Delta f + \bar{x}(r^2K_1 + r^4K_2 + r^6K_3) + (r^2 + 2\bar{x}^2)P_1 + 2\overline{xy}P_2 + \bar{x}B_1 + \bar{y}B_2 \\ \Delta y &= \Delta y_0 - \frac{\bar{y}}{\bar{z}}\Delta f + \bar{y}(r^2K_1 + r^4K_2 + r^6K_3) + 2\overline{xy}P_1 + (r^2 + 2\bar{y}^2)P_2\end{aligned} \qquad (5.1)$$

Inside this model corrections are done with regard to focal length, principal point, radial lens distortion, decentering distortion and affinity and shearing.

The most significant parameters of the single head calibrations of the model are:

The radial distortion parameters:

$$\Delta r = r^3 K_1 + r^5 K_2 + r^7 K_3 , \tag{5.2}$$

and the decentering parameters:

$$\begin{aligned} \Delta x_d &= (r^2 + 2\overline{x}^2) P_1 + 2\overline{xy} P_2 \\ \Delta y_d &= 2\overline{xy} P_1 + (r^2 + 2\overline{y}^2) P_2 \end{aligned} \tag{5.3}$$

The other parameters are typically much less significant. The residuals of a calibration of a single panchromatic camera head system (completely mounted with a CCD-unit) to this model is less than 1/20 of a pixel (< 0.6 µm).

5.1.2 Calibration Process

The calibration of a RMK Top is done using a collimator to determine the distortions directly at image space side. This is normally done for each quadrant of the camera. Since this measurement is not possible directly at a digital camera (one can not look through a CCD), one has to use another approach for the calibration.

Therefore, a collimator generates a target which is photographed by the digital camera. The collimator delivers a well known position (angle) of the target. Changing this angle delivers a series of measurements. Using an intensity-based least squares matching the position of the target on the CCD is determined. This matching determines the positions of the targets by matching each single target to the others. After this matching step, the positions and angles are used inside a bundle block adjustment with self calibration for the computation of the parameters. Additionally, to the unknowns of the Australis model for each series of measurement three unknowns are added to model the exterior orientation of the camera inside the calibration environment. This calibration procedure was jointly developed with the Institute for Photogrammetry of Stuttgart University. The figure 4 below shows a 7k x 4k panchromatic and a 3k x 2k multispectral camera head of the DMC.

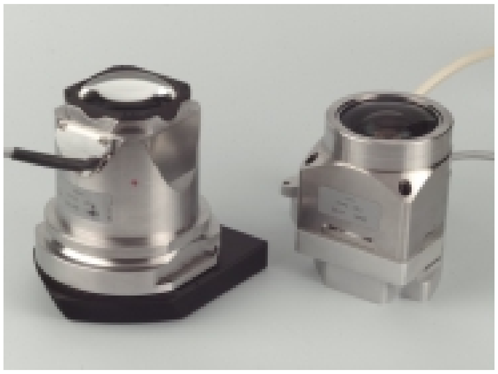

Figure 4: Panchromatic (left) and multispectral (right) camera heads

5.2 Camera Head Radiometric Calibration

The radiometric calibration is applied to each single head of the DMC, too. This calibration is used to correct the different light sensitivities of each single pixel of a CCD. For this correction, a standard approach is used which corrects this influence by doing a gain and offset correction. In addition, the operating conditions can be corrected. A functional model is developed to correct the influences of temperature and aperture size. The resulting image is free of those influences.

The electronics of the CCD matrix sensors, which are used in the DMC camera heads can be operated in TDI mode. This allows a fully electronic FMC of the digital image [Hinz 2001]. In this way, compensation of image blur is assured as it is standard in film-based cameras. Therefore, the functional model has to take in consideration the number of used TDI shifts used during the exposure cycle. For multispectral images, one further correction is done to remove the distortions which are generated by the used filter.

The figures following below show several images before and after the radiometric correction which contains the correction for defect pixels, too. Figure 5 shows an overview of a construction site before (left) and after (right) the radiometric correction was applied. One can see quite well the improvement of the contrast inside this image. Another advantage of the corrected image is the reduction of noise which is reached by the radiometric correction of each single pixel.

Figure 5: Original (left) and radiometric corrected (right) image

Another advantage is the fact that *scratches on the film* are well known. Those scratches are the defect columns which can be inside a CCD. But the positions are well known and can therefore be corrected automatically. The result of such a defect column correction is shown in figure 6.

Figure 6: Image cut containing a defect column (left) and corrected image (right)

As described above, single pixels can have less light sensitivity (electronically influenced). Another problem is that during the production of CCD parts of dust later on darken some pixels and therefore those pixels would be less light sensitive. This influence is also collected by the radiometric calibration procedure and applied during the radiometric correction which takes place in the post processing system. Figure 7 shows on the left side in the middle of the image such a cluster of less sensitive pixel elements and on the right side the corrected image. The distortion was totally eliminated.

Figure 7: Defective image (left) and corrected image (right).

6. CALIBRATION OF THE EIGHT HEAD CAMERA PLATFORM

6.1 Platform Geometric Calibration

The camera platform calibration consists of two main tasks. First, the mounting of the four panchromatic camera heads relative to each other must be exactly known to ensure that the resulting image mosaic is correct and useful. Second, the color channel images must be combined with the mosaicked high resolution panchromatic image. Before describing the calibration procedures, a short overview about the used platform coordinate frame is given.

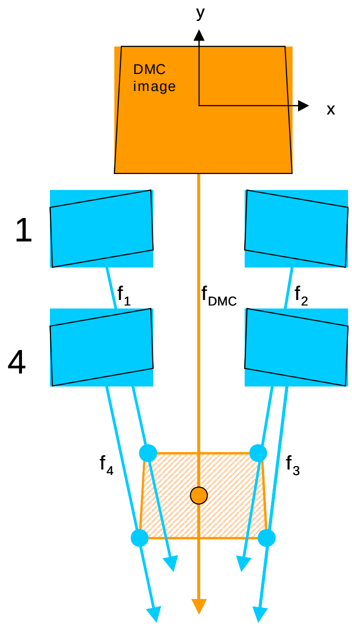

Figure 8: Virtual DMC projection center (orange dot) vs. real projection centers of the panchromatic cameras 1,2,3 and 4 (blue dots).

Figure 8 gives an overview about the platform coordinate system of the DMC. The focal lengths f_1,f_2,f_3 and f_4 are calibrated separately, the focal length f_{DMC} is generally freely selectable, but mostly defined to 120 mm. This ensures that the recorded pixel have nearly the same size as the pixel in the image mosaic. The virtual DMC projection center of the virtual camera is the center of the plane which is defined by the projection centers of the four panchromatic cameras. Small deviations in height of the nodal points from the plane are not relevant, because the resulting shifts in the image mosaic are very small and can therefore be neglected. The mounting of a panchromatic camera inside the DMC platform can be modeled by a set of *exterior orientation* parameters, which means by 3 position coordinates in combination with 3 orientation angles. In a calibration step the position of each panchromatic projection center with respect to the defined *virtual* projection center is derived from the construction information.

The three orientation angles are determined using a bundle block adjustment (BBA). As input of the BBA, image coordinates of tie points in the small overlapping areas are generated in an automated process. The BBA results are the mounting angles φ, ω and κ for all four panchromatic cameras, while the small differences in X,Y,Z can be neglected. Normally, the derived values should guarantee an exact matching of the images. However, for verification purposes, residual shifts between the image tie points are determined using an affine transformation. If shifts are still obtained, they are transformed into small angle increments which are applied to the adjusted φ, ω and κ values. Together with the calibrated focal lengths of the pan heads and the properties of the "virtual" DMC camera (position of projection center, focal length f_{DMC}) all information is available to perform the mosaicking of the four pan heads into one large DMC image.

After determination of the pan camera head mountings, the resulting image mosaic is scaled down to the size of the color images. Between this small pan image and the green channel image, an interest point operator in combination with a least-squares-matching procedure is applied. The computed tie point coordinates are serving as input into the determination of projective transformation parameters which do the mapping between the two input images. The red and the blue color channel images are registered to the green channel image in the same way. Finally, a set of three projective transformation parameters (red → green, blue → green and green → pan) is available. After enlarging the color channel images to the size of the high-resolution pan image, the fusion of all single images into one DMC RGB image is performed by applying the geometric transformation parameters. The false color infrared image is processed in a similar manner.

6.2 Platform Radiometric Calibration

Each of the involved camera heads are radiometrically calibrated as described chapter 5.2. These information is applied when the images are processed. Therefore, one can expect that the mosaicked DMC image has not to be reworked with respect to the radiometry. However, small intensity discrepancies between adjacent panchromatic images may remain. To correct for this, a histogram of the pixels in the overlapping regions of the images will be derived. Using this data, an optimization of the intensity values is computed and applied during the mosaicking process.

7. CONCLUSION

Today, aerial photography is a mature film-based process that has been developed now for nearly 100 years. With the market introduction of the DMC, a high resolution digital photogrammetric camera will become available. An overview about the DMC concept and its realization was given. The described DMC multi camera approach offers high geometric accuracy for photogrammetric applications. This high intrinsic accuracy is determined by the two dimensional matrix of CCD pixels structured on a silicon wafer. The resulting digital image has the usual central perspective geometry, thus maintaining compatibility with existing softcopy solutions.

Several steps of the DMC calibration procedure have been shown. The geometric calibration of a single camera head contains the calibration of the geometry as well as the calibration of the radiometry. Therefore the resulting image of the Post Processing later on is free of distortion in geometry and radiometry. The geometric camera platform calibration determines the relative mounting of the four high resolution panchromatic camera heads. This relative orientation ensures that the quality and accuracy of the resulting image mosaic.

At the time of writing of this article (January 2002) the first fully equipped DMC camera unit ready and waiting for appropriate photoflight weather to precede its maiden photogrammetric flight-test. The described calibration procedure will be used for first photogrammetric operation of this new camera system which scheduled for spring and early summer 2002.

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