GEOMETRIC CALIBRATION OF THE DIGITAL LARGE FORMAT AERIAL CAMERA ULTRACAM$_D$

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ABSTRACT:

The evaluation of the geometric performance of the novel digital large format camera UltraCamD is the topic of this presentation. We describe the concept of the geometric calibration by means of a bundle adjustment. Based on the specific design of the camera additional parameters were defined and the bundle adjustment software BINGO was modified in order to handle these parameters.
The entire calibration procedure consists of four phases. In the first phase a set of images of a well defined geometry target is taken in such way, that highly redundant observations are possible. The second phase is dedicated to image coordinate measurement. Automation and accuracy is derived by image processing techniques exploiting the specific shape of the well defined targets. The third phase consists of the semi automatic adjustment process, where unknown parameters of the camera (e.g. focal length and principal point coordinates, distortion parameters and additional parameters) are estimated. In phase four we distinguish between linear and non linear parameters. Linear parameters are used to reduce the linear effect of distortions of the camera. This is achieved by a linear transform of the measured coordinates in such way, that only small nonlinear effects remain. Those effects are then described in a look up table.
The results from a full calibration campaign, the adjusted parameters and the effect of these parameters are presented. Finally the calibration is approved and justified.

1. INTRODUCTION

1.1 General Remarks

UltraCamD is a metric camera, designed for precision photogrammetric applications. Thus the interior geometry of UltraCamD is determined through a calibration procedure. The basis for the calibration is a set of images from a well defined and precisely surveyed control point field.
The mathematical background of the calibration procedure is the co-linearity equation as it is known from traditional analog camera (i.e. the model of the pinhole camera). Thus focal length and principal point coordinates are the first order parameters of UltraCamD.
A second set of parameters are determined to describe the radial symmetric and other distortions of the optical system in line with the traditional photogrammetric doctrine.

In addition to these well known parameters (parameters of the pinhole camera plus lens distortions) a third set of parameters is involved in the UltraCamD geometric calibration.
These parameters describe the position of each CCD sensor in the focal plane of each of the eight cones of UltraCamD.

The determination of these parameters is performed through a bundle adjustment procedure offered by the BINGO software package.

The parameters derived through the calibration procedure build up the full geometric description of each cone of the UltraCamD. The internal linear transformation between cones is determined by a stitching process, based on highly redundant tie point matching results.
Calibration parameters and internal transformation parameters are then used to produce the distortion-free UltraCamD output image.

2. THE ULTRACAM$_D$ DESIGN CONCEPT

2.1 ULTRACAM$_D$ SENSOR UNIT (SU)

The sensor unit of Vexcel's UltraCamD consists of eight independent cameras, so-called cones. Four of them create the large format panchromatic image at a size of 11500 by 7500 pixels. The other set of four cones is responsible for the multi spectral channels of the UltraCamD, i.e. red, green blue and near infrared (Figure 1).

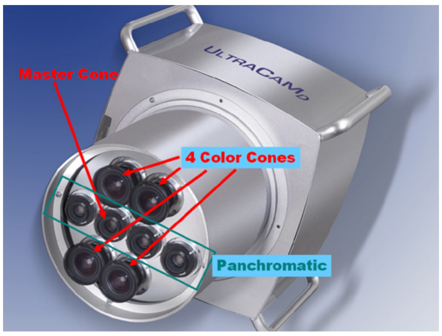

Fig. 1: UltraCamD Sensor Unit

The panchromatic part of the camera combines a set of 9 medium format CCD sensors into a large format panchromatic image. The multispectral channels are supported by four additional CCD sensors.
Each of these 13 CCD sensors is the front end of a separate imaging module. It consists of the sensor, the sensor electronics, a high end analog/digital converter (ADC) and the IEEE 1394 data transfer unit.
The raw image data is transferred via the IEEE 1394 interface to a separate storage module of the Storage and computing Unit of UltraCamD.
Thus the camera offers a frame rate of more than 1 frame per second, exploiting the benefit of its parallel system architecture.
The panchromatic image consists of 11500 pixels cross track and 7500 pixels long track. Color is simultaneously recorded at a frame size of 4k by 2.7 k pixels for red, green, blue and near infrared [Leberl 2003].

2.2 Multi-Cone Design of the Camera Body

The geometric performance of the camera is defined by the so-called "master cone", which consists of four CCD sensors and one single optical system. The four CCDs define the large format panchromatic image of the UltraCamD. The gaps between these four sensors are filled by the other three panchromatic cones. The transformation between cones is determined by the calibration and is being confirmed on line, i.e. for each frame, by tie point matching. We denote the merging of the individual image segments into a full-format image by "stitching" (Figure 2).

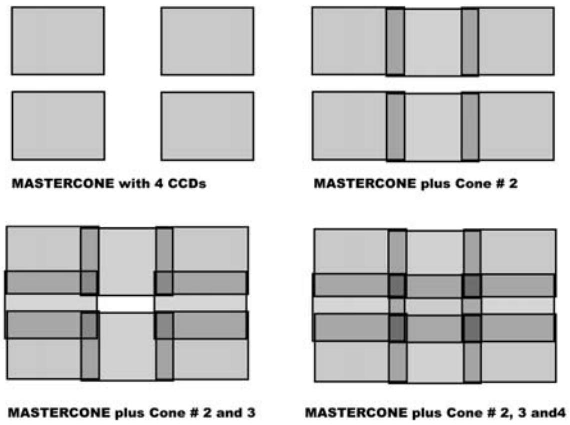

Fig. 2: The backplanes of four cones of the panchromatic channel produce a set of 9 sub-images. These get sequentially grouped in 3 steps, where 4 formats exist, which we denote as "layers". The master cone on the upper left with its 4 CCDs defines the geometry of the large format image.

3. CALIBRATION TARGET

The calibration target is established in a room in the basement of Vecxel's office building. Its dimensions are 330 cm by 220 cm by 200 cm. Three fixed camera stations are available.

The target consists of 240 well defined points, surveyed at an accuracy of +- 50 µm in X, Y and Z. The points are fixed on the rear wall, the sidewalls, the ceiling and the floor.
Four additional points are established in a central position of the target volume (Fig. 3).

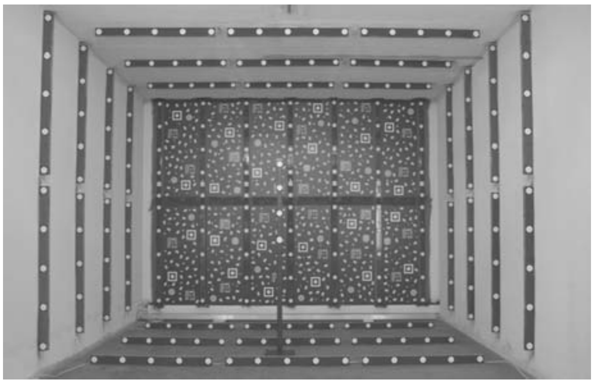

Fig. 3: Calibration test field in the basement of Vexcel's office building. The test field consists of 240 precisely surveyed control points.

3.1 Data Capture

The data capture, i.e. the taking of images with the camera, is done from the three camera stations. Tilting and rotating the camera leads to a set of images from each station. In such sets we derive high redundancy and excellent distribution of measurements in the image plane. Exposure time and aperture of the lenses are tuned for the specific application. In order to derive a reasonable sharpness in the images at a limited object distance, a small aperture, (f 1/11) and a rather long exposure time of 3 sec is chosen.

A set of 84 images is taken from three image stations by rotating and tilting the camera .

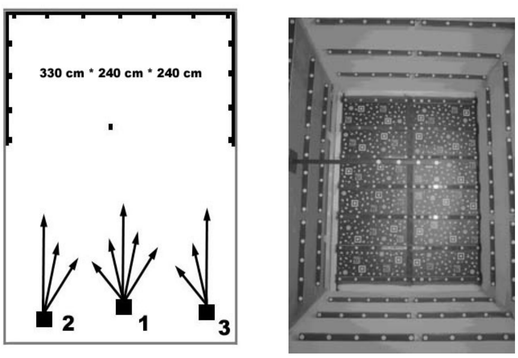

Fig. 4: Three Camera positions are established (left) and a set of 84 images is produced by rotating and tilting (right) the camera.

3.2 Image Coordinate Measurement

The image coordinate measurement is supported by special software tools. For the manual approach a zoom window is displayed and control point positions are measured within steps of a quarter of a pixel. The final set of image coordinates of the point targets is based on digital image processing techniques and approximations from the manual measurements (Fig. 5).

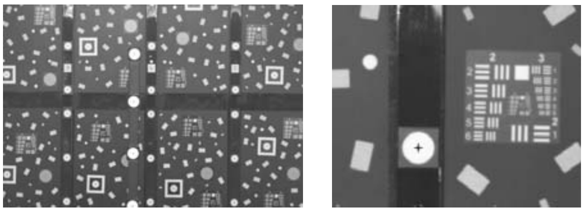

Fig. 5: Sample image of the calibration target (left) and the result of an automated detection of one point target (right)

The full set of image coordinates measured from 84 images consists typically of about 14 000 positions within the set of panchromatic cones and even more for the multispectral cones of UltraCamD. The precision of the target detection algorithm was investigated and a deviaton of about +/- 1.3 µm (i.e. 0.14 pixel) has been observed (Fig. 6).

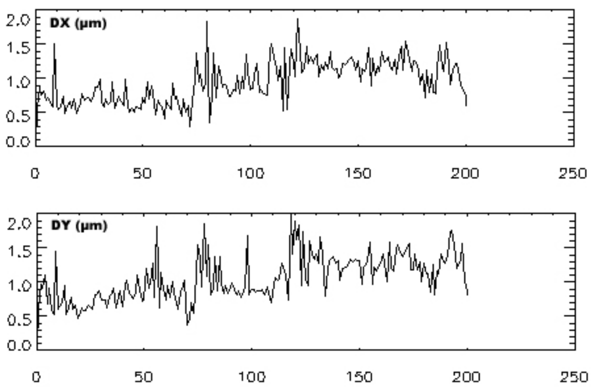

Fig. 6: Deviation of measured image coordinates of 200 target points in the set of 84 images in x-direction (top) and y-direction (bottom)

4. ESTIMATION OF CAMERA PARAMETERS BY MEANS OF LEAST SQUARES ADJUSTMENT

The adjustment of all image coordinate measurements and the estimation of camera parameters is performed with the software package BINGO. The entire adjustment procedure is fourfold:

- Calculation of the initial solution of camera parameters including parameters of CCD position, principal distance and principal point coordinates and lens distortion.
- Transformation of image coordinates (the measurements) to clear CCD position parameters. This step needs several iterations in order to avoid any eccentricity of the radial distortion parameters of the lens cone.
- Description of remaining displacements in the image plane and description of the displacements by means of a look up table.
- Estimation of transform parameters between cones in order to guide the post-processing (stitching) of the large format panchromatic image and the registration of the multispectral channels to the panchromatic image (pansharpening).

4.1 Results

The adjusted parameters and the look up tables are stored together in a calibration data set. This dataset is automatically used during the postprocessing by software. The final output image (production image) of the UltraCamD is distortion free, the remaining set of camera parameters which need to be known by the user consist of the well known parameters of a pinhole camera, namely the principal distance and the coordinates of the principal point.
The standard deviation of these parameters is recalculated after the calibration process and expected to be less then +/- 2 µm.

5. CONCLUSIONS

The multi-cone/multi-sensor concept of UltraCamD demands a specific calibration method. This calibration method is based on a highly redundant set of image coordinate measurements and a least squares solution of the well known bundle adjustment technology. New parameters have been introduced in the adjustment software package BINGO to model UltraCamD, its cones and lenses as well as the set of 13 CCD sensors.
The output of the adjustment is a precise description of the camera geometry, including CCD position, principal point coordinates, principal distance and lens distortion parameters.
The accuracy of the calibration method was analyzed by exploiting the flexible stochastic model offered by BINGO. To quantify the result by a single number we have used the sigma_o value after the adjustment. This value has been detected to be in the range of +/- 1.0 µm to +/- 1.5 µm for all calibration session done so far.

6. REFERENCES

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