CALIBRATING THE DIGITAL LARGE FORMAT AERIAL CAMERA ULTRACAM$_X$

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ABSTRACT

We present the method of the geometric calibration of the digital large format camera UltraCamX. The entire process consists of three major steps: the laboratory calibration, the stitching process and the self calibration process. The laboratory calibration is based on a highly redundant set of images from a 3D calibration target. The initial calibration dataset is computed by means of a least squares bundle adjustment with specific parameters. These parameters provide the basic geometric description of the sensor.

Within the post-processing of each frame after the flight mission the transformation parameters between layers of the multi cone design are computed via a so called stitching method. This stitching method was improved and includes physical parameters of the camera body. Finally we improve the geometric performance of the camera system by introducing self calibration capabilities into the process of the aero-triangulation. Such self calibration parameters are estimated by means of a least squares bundle adjustment.

The geometric lab calibration for the UltraCamX has been optimized by the new calibration facility. This was established in mid 2006 when Vexcel Imaging GmbH moved into a new office building.

INTRODUCTION

UltraCamX is the new large format digital aerial mapping camera of Vexcel Imaging GmbH and was introduced to the international mapping market at the ASPRS 06 conference in Reno, Nevada. The camera is based on Vexcel's well known multi cone design concept [Gruber, 2007]. This concept was actually presented in 2003 together with the UltraCamD camera system [Leberl et al., 2003]. It is further noteworthy, that Vexcel Imaging GmbH was acquired by Microsoft Corp. in 2006 and continues to manufacture, offer and maintain the camera system.

ULTRACAMX LARGE FORMAT DIGITAL FRAME CAMERA

UltraCamX is the successor of the UltraCamD camera system. The most significant advantages of the camera system are

- large image format (14430 pixels cross track and 9420 pixels along track, new 7.2 µm CCD sensors @ 16 MPix)
- new optical system (100 mm focal length for the panchromatic camera heads and 33 mm for the multi spectral camera heads)
- image storage capacity of 4700 frames (~ 2 TeraByte)
- instant data download from the airplane by removable data storage units
- fast data transfer to the post processing system by the new docking station

The camera consists of the sensor unit, the onboard storage and data capture system, the operators interface panel and two removable data storage units. Software to operate the camera and to process the image data after the flight mission completes the system.

Fig.1: UltraCam X digital aerial camera system with Sensor Unit (right) and Airborne Computing Unit including two removable Data Units (left).

The basic design of the UltraCamX sensor head is similar to that of the older UltraCamD. It consists of eight independent camera cones, 4 of them contributing to the large format panchromatic image, 4 contributing to the multi spectral image. The sensor head of the UltraCamX is equipped with 13 FTF5033 high performance CCD sensor units, each producing 16 mega pixels of image information at a radiometric bandwidth of more than 12 bit.

The transition to 7.2 µm CCD sensors caused a redesign of the optical system which is now able to resolve the 70 lp/mm of the CCD pixel grid. In cooperation with LINOS/Rodenstock such high performance optical system with the focal length of 100 mm for the panchromatic cones and the focal length of 33 mm for the multi spectral cones was developed. This set of two lenses supports the pan sharpening ratio of 1:3.

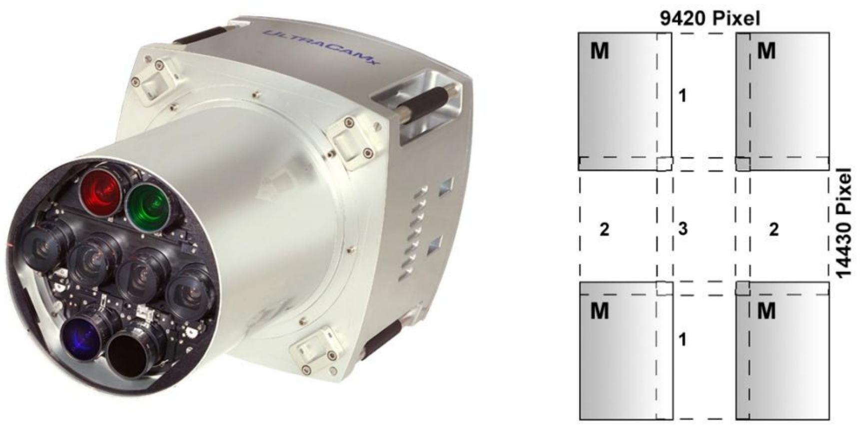

Fig. 2: The UltraCamX sensor head (left) consists of 8 camera heads, 4 of them contributing to the large format panchromatic image. These 4 heads are equipped with 9 CCD sensors in their 4 focal planes.
The focal plane of the so called Master Cone (M) carries 4 CCDs (right).

Technical Data UCX Sensor Unit	
Panchromatic Channel	
Multi cone multi sensor concept	4 camera heads
Image size in pixel (cross track/along track)	14430 * 9420 pixel
Physical pixel size	7.2 micron
Physical image format (cross track/along track)	103.9 mm * 67.8 mm
Focal length	100 mm
Lens aperture	f = 1/5.6
Angle of view (cross track/along track)	55° / 37°
Multispectral Channel	
Four channels (Red, Green, Blue, Near Infrared)	4 camera heads
Image size in pixel (cross track/along track)	4992 * 3328 pixel
Physical pixel size	7.2 micron
Physical image format (cross track/along track)	34.7 mm * 23.9 mm
Focal length	33 mm
Lens aperture	f = 1/ 4
General	
Shutter speed options	1/500 sec – 1/32 sec
Forward motion compensation	TDI controlled, 50 pixels
Frame rate per second	1 frame in 1.35 sec
A/DC bandwidth	14 bit (16384 levles)
Radiometric resolution	> 12 bit /channel

Tab. 1: Technical Data and Specifications of the UltraCamX Senor Unit

THE ULTRACAM CALIBRATION LABORATORY

Vexcel's new Calibration Laboratory after the move into a new office building is in use since July 2006. It consists of a three dimensional calibration target with 367 circular marks. These marks are surveyed to an accuracy of about +/- 0.1 mm in X, Y and +/- 0.2 mm in Z and show a well defined circular pattern. The dimensional size of the entire structure is 8.4 m by 2.5 m at the rear wall and 2.4 m in depth. Rear wall, ceiling and floor carry 70 metal bars with 280 marks; four additional vertical bars in the center of the structure carry 16 marks; 98 marks are mounted at the rear wall. The mean distance between marks is about 30 cm.

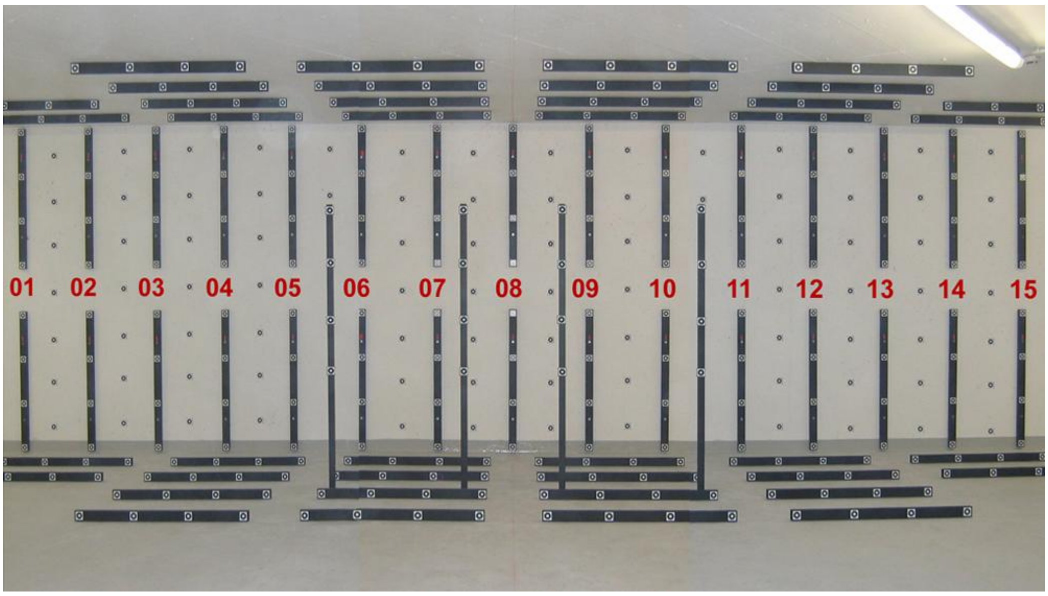

Fig. 3: The UltraCam calibration laboratory is equipped with a three dimensional target which contains 367 marks. The size of the entire volume is 8.4 m by 2.4 m by 2.5 m.

During the data capture 84 images are taken from three different camera stations in such way that the camera is tilted and rotated.
Software is used to compute sub-pixel accurate image positions of each mark in each image of the entire set of images. This results into a dense and complete coverage of coordinate measurements over the entire the image format. Figure 4 shows the distribution of measured points. In One single calibration dataset consists of almost 90 000 measured image points.

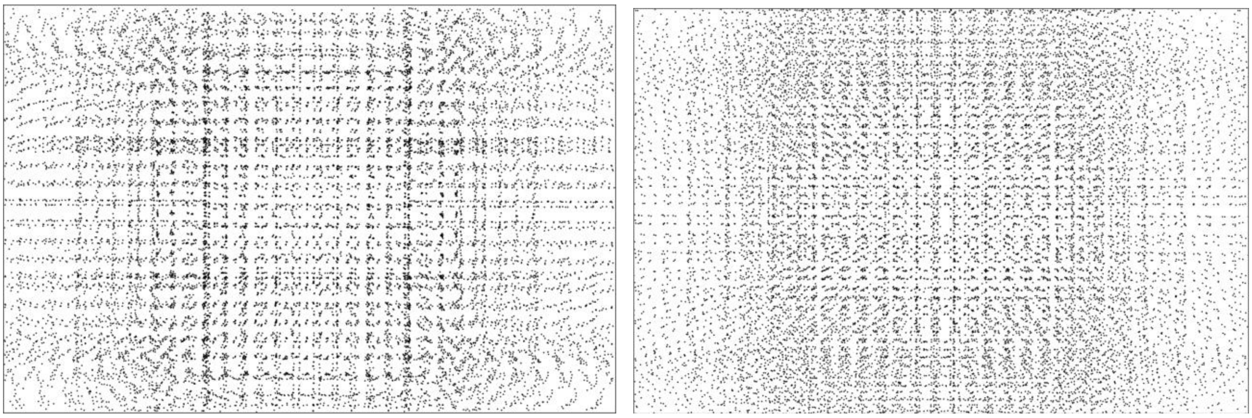

Fig. 4: The automatically detected image positions cover the entire frame of the camera. About 18500 points are detected in the panchromatic channel (left) and 17500 points are detected in each of the four color bands.

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COMPUTING CAMERA PARAMETERS

The computation of the unknown camera parameters is based on the least squares bundle adjustment method by BINGO [Kruck, 1984]. The specific design of the UltraCamX sensor head made modifications in the bundle software necessary. It was most important to introduce the ability to estimate the positions of multiple CCD sensor arrays in one and the same focal plane of a camera head.

The unknown parameters which are estimated within the bundle adjustment procedure can be separated in three groups:

- The traditional camera parameters to define the bundle of rays (principal distance and coordinates of the principal point);
- The specific UltraCam parameters for each CCD position in the focal plane of each camera cone (shift, rotation, scale and perspective skew of each CCD);
- Traditional radial and tangential lens distortion parameters (for each lens cone).

When investigating the correlation between those parameters it is obvious that CCD scale parameters are correlated with the principal distance of each cone and CCD shift parameters are correlated with the principal point coordinates of each focal plane [Gruber, Ladstädter, 2006]. It was therefore necessary to reduce the entire set of parameters in order to avoid such correlation. This was done in such way that principal distance and principal coordinates of all eight cones of the UltraCamX were introduces as constant values. It is further noteworthy that there exists an additional correlation between the CCD rotation parameter and the angle kappa of the exterior orientation. This correlation could be resolved by removing one and only one CCD rotation parameter of the parameter set of each camera head [Kröpfl et al., 2004].

The resulting quality of the geometric lab calibration is documented by the sigma_o value of the bundle adjustment. This value was observed at a level of 0.4 µm to 0.5 µm for all calibrations of the panchromatic camera cones carried out in the new calibration laboratory. This is a slight but significant improvement compared to the results achieved from the old calibration laboratory which was in use until mid 2006.

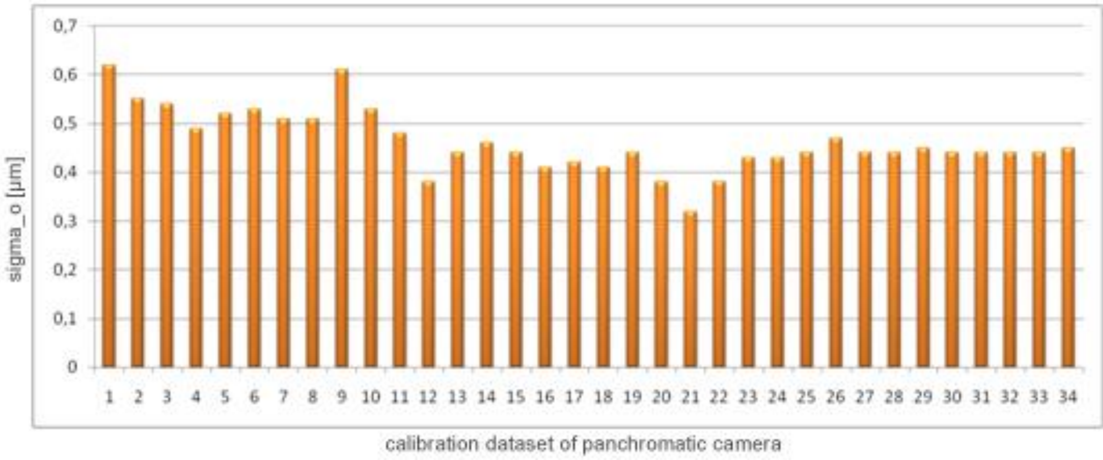

Fig. 5: Results of the bundle adjustment after the estimation of camera parameters (panchromatic camera). Sigma_o values of the adjustment are in the range of 0.4 µm to 0.5 µm. Slightly larger values (0.5 µm to 0.6 µm) were observed from the old calibration laboratory which was in use till mid 2006.

POST-PROCESSING AND ADDITIONAL IMPROVEMENTS

The results from the laboratory calibration are stored in a data set which is used during the post processing of each frame which was exposed by the camera. During this post-processing we apply parameters which are able to describe dimensional changes of the camera body which may be caused by the change of environmental parameters during a flight mission (e.g. any thermal effect). Such thermal changes cause symmetric expansion/shrinking of the backplanes of the UltraCam cones. The CCD mounted on the backplane will therefore "drift away" from their calibrated positions when temperature during flight deviates from temperature at calibration time. If this effect is neglected in the stitching process, systematic image deformations will be visible in the images.

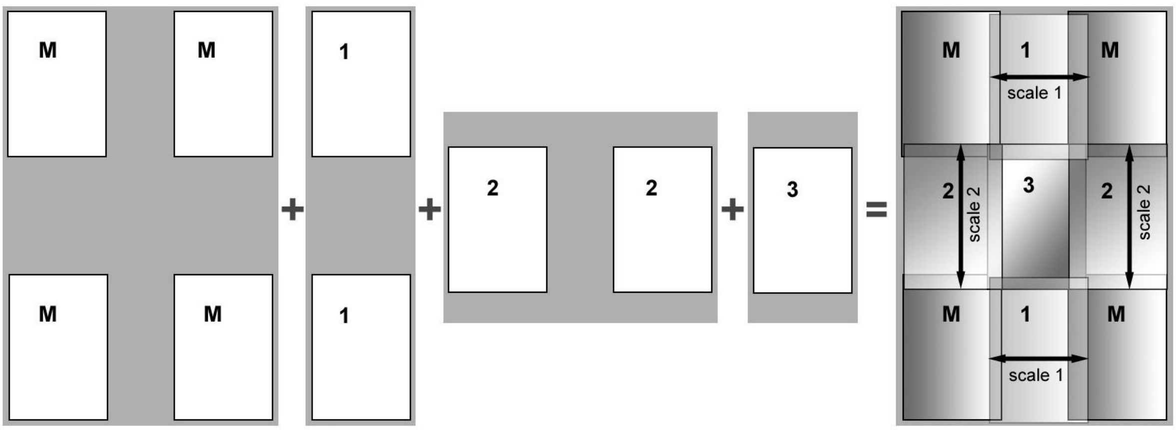

Fig. 6: Scheme of the UltraCam stitching concept which is implemented in the image post-processing in order to transform the image information of the four camer heads into one single frame. The two scales shown on the right are computed during this step and compensate for any dimensional changes of the camera body.

These self calibration parameters are deduced from the stitching scales scale1 and scale2 and the well known distances between the stitching zones. Sensor drifts can now be modelled and compensated. Finally a 2^{nd} stitching procedure is performed using the modified calibration parameters. The stitching scales are expected to be close to 1.0 after the self calibration has been applied. This self calibration method has been introduced successfully into the post processing software of the UltraCam digital camera system [Ladstädter, 2007].

GEOMETRIC ACCURACY AT THE 1 MICROMETER LEVEL

After the geometric laboratory calibration the performance of every UltraCamX is verified by a flight mission over a well known test area. A flight pattern with high overlap (80% endlap, 60% sidelap) and cross strips offers a redundant dataset which allows to investigating the interior geometry of the camera.

The automatic tie point matching was done using INPHO’s aerial triangulation software packages Match AT. A cross check and additional self calibration options were applied by BINGO.

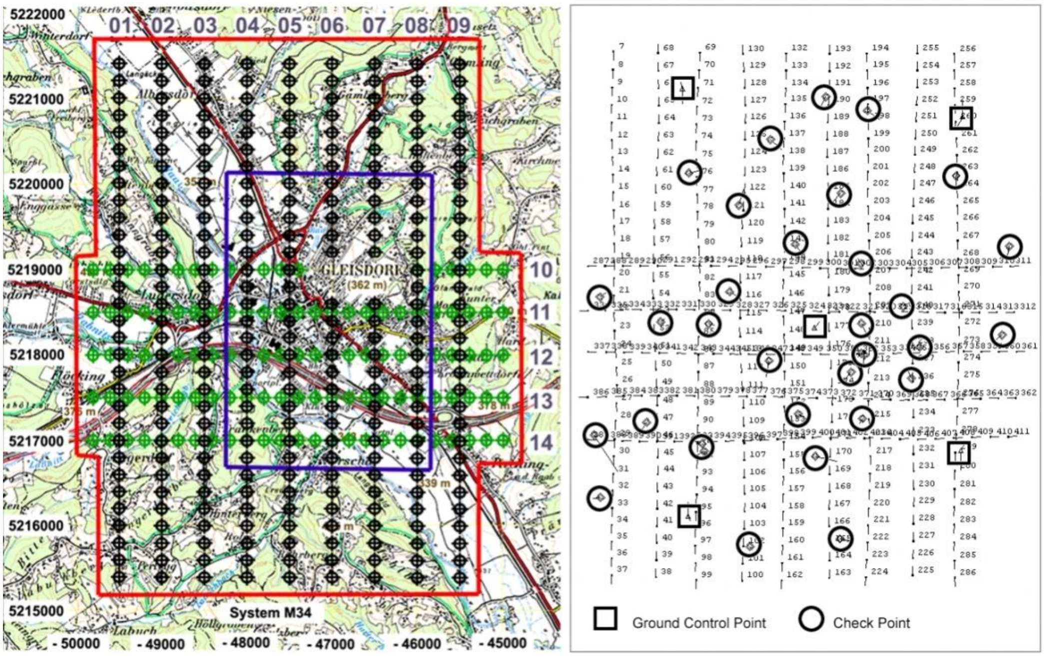

Fig. 7: Test area near Graz, Austria. Flight plan with 14 flight lines (404 images) and the result of the AAT after an UltraCamX photo mission (processing by Match AT and BINGO software).

The sigma_o value reflects the quality level of image coordinate measurements of an aerial triangulation project. Such values have been computed for several UltraCamX image datasets. The sigma_o values of the flight missions shown in Figure 8 are close to or smaller than 1 µm at that huge redundancy of high overlaps and additional cross strips.

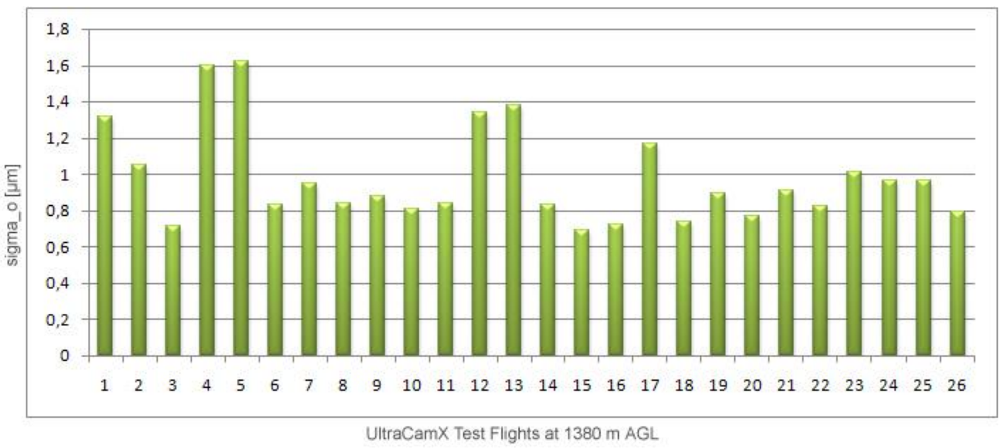

Fig. 8: Results of the Automatic Aerotriangulation from several UltraCamX testflights at 10 cm GSD (1380 m AGL). Sigma_o values are in the range of 0.7 µm to 1.6 µm. The average value of sigma_o is less than 1 µm

Another widely accepted method to proof the geometric performance of mapping cameras is the use of check points. We use the result of 6 individual flight missions and 6 individual cameras to analyze the geometric performance of these cameras. Averaging 199 check point measurements a deviation of 38 mm, 46mm and 56 mm in X, Y and Z was observed. The vertical accuracy of that dataset corresponds to 0.04 o/oo of the flying height (cf. Fig. 9).

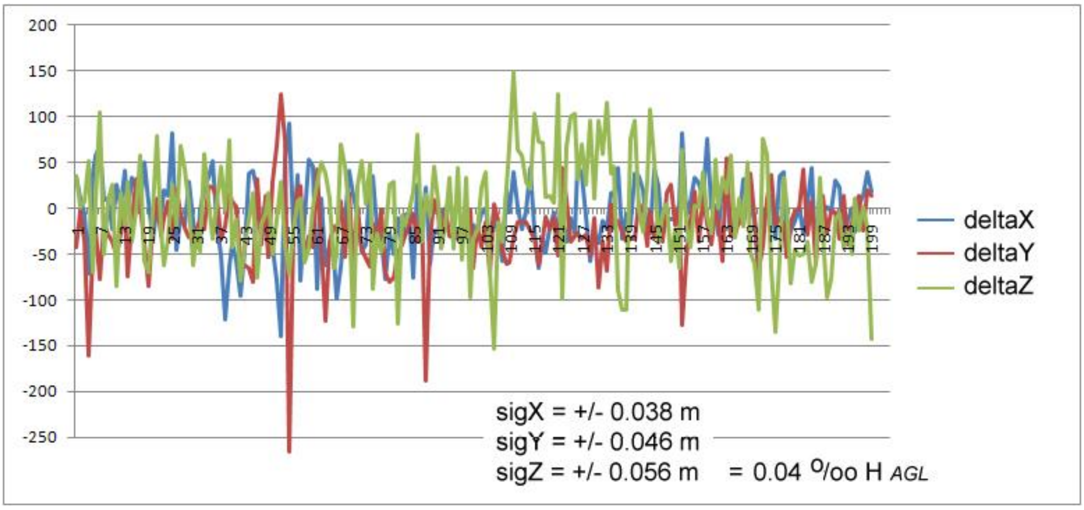

Fig. 9: Residuals of check points after the bundle adjustment. Results from 6 individual cameras and flight missions were merged and 199 measurements from almost 35 checkpoints were analyzed.

GEOEMTRY IMPROVEMENT BY AUTO CALIBRATION

The end-to-end digital workflow of the UltraCam processing chain offers several auto calibration capabilities. One specific function is already implemented in the post processing software and reduces effects of thermal changes during a flight mission (cf. Fig.6). In addition we have observed positive effects when traditional radial symmetric distortion parameters were introduced into the bundle solution. Such parameters are well known in the community and almost any bundle solution offers and almost any digital workstation is able to accept such parameters. The magnitude of those parameters is small (< 0.5 Pixel) but their effects are systematically and shall not be ignored. In addition to the widely known radial symmetric distortion parameters we have investigated the positive effect of camera specific parameters.

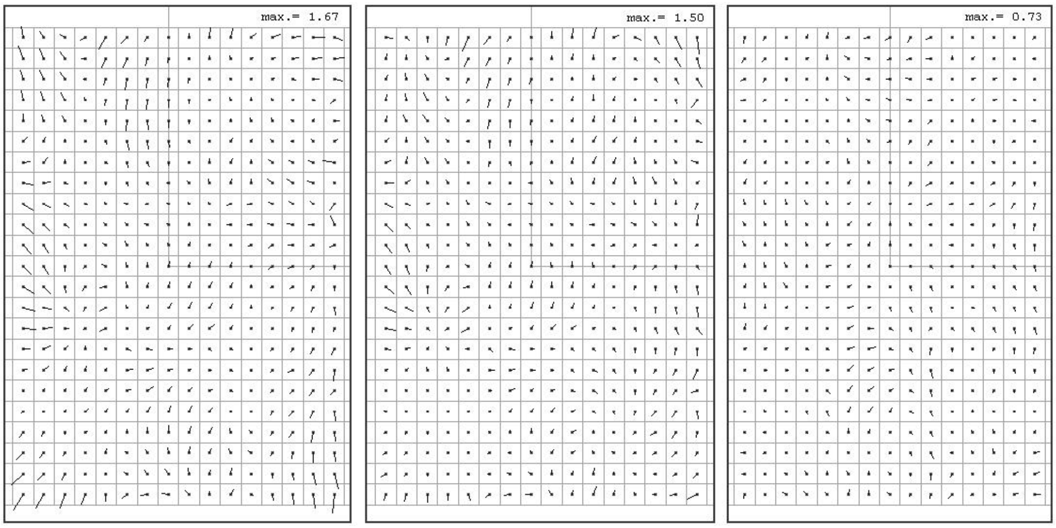

Fig. 10: Image residuals after the aerotriangulation w/o additional self calibration parameters (left), radial symmetric distortion parameters (middle) and camera specific parameters (right).

Those parameters are introduced in order to compensate for any other asymmetric changes of the geometry of the camera. Again, the magnitude of those parameters is expected to be rather small but will play a role when high accuracy is expected. The result of such sequence of corrections is shown in Figure 10. The remaining residuals in the images have a maximum at 1.67 µm when no additional self calibration parameters are applied. In the case of radial symmetric distortion parameters this maximum value decreases to a value of 1.5 µm and finally, after applying additional asymmetric parameters to a value of 0.73 µm only.
When automatic self calibration is applied, one expects that systematic image errors are stable and do not change during the flight mission. This stability is a clear advantage of the digital camera over the film camera and has been already documented.

CONCLUSION

The geometric performance of the digital aerial camera UltraCamX was presented. Furthermore components of the entire data processing workflow were lined out. The laboratory calibration was evaluated and results at a remarkable quality level were documented. In addition to the lab calibration the advanced stitching process and variations of a self calibration were shown. Finally results from several flight missions were presented and show the potential of the camera.

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