GEOMETRIC ANALYSIS OF VEXCEL IMAGING ULTRACAM$_X$ TEST FLIGHTS

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ABSTRACT:

In this paper we present the results of test flights performed with the large format digital photogrammetric camera system UltraCamX. Test flights are performed on a 5*7 sqkm large test site near Graz. Overall 520 images are captured in two different flying heights (GSD 10cm and GSD 25 cm). During post-processing high resolution panchromatic and color images are processed in a fully automated workflow from the raw image data. At the same time systematic influences of the image geometry caused by temperature changes are automatically corrected. Information about the stitching process and the temperature correction are written to log files. A first analysis of the geometric quality can already be done using this information. After additional radiometric quality control an automated aerotriangulation (AAT) is performed for both flying heights. This is done with MatchAT (Inpho GmbH, Stuttgart) using the GPS navigation solution for the initial block setup. For each test flight in total 46 ground control points located in the test area have to be manually measured. A final bundle adjustment is done with the software BINGO (GIP, Aalen) using traditional as well as camera specific self-calibration parameters. BINGO is also used for a further analysis of the geometric quality of the UltraCamX system. This includes the visualization and numerical interpretation of certain key parameters like check point residuals, image residuals and self-calibration parameters.

1. INTRODUCTION

The large format aerial camera system UltraCamX is being produced since January 2007. Quality control is done for each camera unit using image data exposed over a 35sqkm test site. Overall 520 images are taken in two different flying heights with a ground resolution of 10cm and 25cm, respectively.

After each test flight raw image data is processed so that the nine subimages of the UltraCamX multi-cone system are composed to a 136 Mpixel large single image. This fully automated workflow includes the analysis of the 12 overlap regions between the separate images. Sensor drift caused by varying temperature is compensated by a temperature dependent correction model (TDM). Finally, the estimation of transformation parameters is performed, which enable the composition of the final images.

The image blocks of both flying heights are triangulated after the image post-processing. This includes the measurement of 46 full ground control points and the fully automated tie point measurement done by MatchAT. Results are exported to the bundle adjustment software BINGO for further analysis.

In this paper we present the results of the geometric analysis of 40 UltraCamX test flights and give detailed information of the effects of additional self calibration parameters on the image geometry.

2. TEST AREA GLEISDORF

In order to check the geometric quality of each UltraCamX unit under production flight conditions prior to delivery, a test site has been setup 30km east of Graz (see Fig. 1). The test site has an extension of 5*7 sqkm. When selecting a suitable area, attention was paid on heterogeneous surface structures (area with height differences, forest, acre, grassland, floodplains, buildings and traffic infrastructure). Based on these objects radiometric quality control is performed in addition to the geometric quality control. In the test area 46 full ground control points (GCP) have been measured with an positioning accuracy of 3cm using differential GPS.

Each UltraCamX camera system manufactured is being flown in two different flying heights (1500m and 3500 AGL). In the lower flight (10cm GSD) 404 images and in the higher flight (25cm GSD) 116 images are captured, respectively. The flight pattern includes several cross strips. Forward overlap of 80% and side overlap of 60% is used. In addition to the image data, GPS and INS Data are recorded.

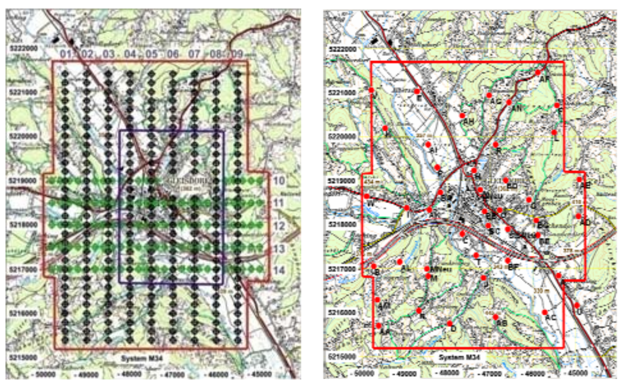

Fig.1: Test site Gleisdorf: flight pattern (left) and GCP (right)

3. IMAGE POST PROCESSING

3.1 Stitching of the PAN image

The UltraCamX is based on a multi sensor concept (cp. Leberl et al., 2003). During image post-processing with Vexcel's Office Processing Center (OPC) the high resolution panchromatic image has to be stitched together from separate images from a total of nine CCD sensors. For this purpose stitching points are matched in the twelve overlapping zones of the nine subimages.

When we analyse the results of the stitching process we find a very high point matching accuracy (below one tenth of a pixel, see Fig. 2) and a high percentage of matched points (about 90%, see Fig. 3). This information can be found in the OPC log files which are generated for each frame.

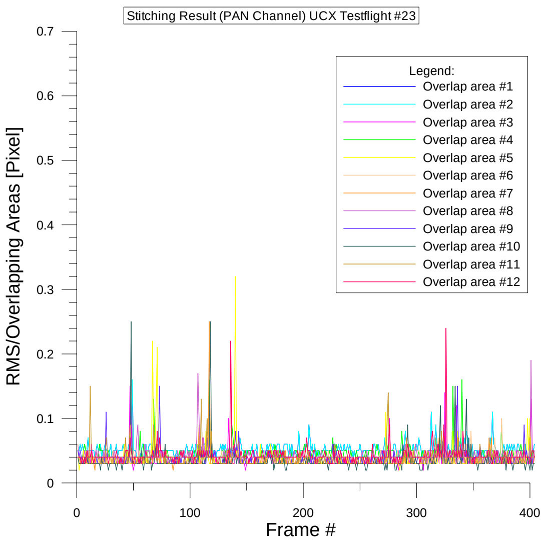

Fig 2: RMS error of matched stitching points

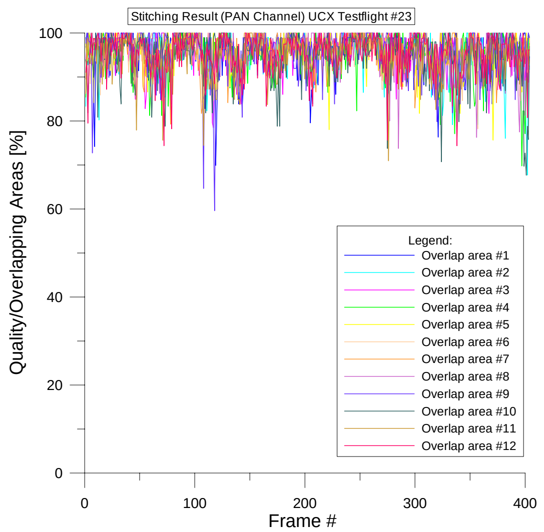

Fig 3: Percentage of successfully matched stitching points

3.2 Temperature dependent correction model

Within the camera calibration the position of each of the CCD sensors in the camera cones is determined precisely. These calibration parameters are valid for a certain temperature at calibration time. During test flights different temperature conditions affect the camera components. Thus, a temperature difference *dC* causes small sensors drifts in the focal plane. To compensate for the sensor shifts, a robust temperature dependent correction model (TDM) has been developed at Graz University of Technology (cp. Ladstädter, 2007, Ladstädter & Gruber, 2008).

The temperature difference *dC* needed to model the sensor drift is derived from the stitching scales. The temperature difference estimated by TDM is verified and cross-checked by analysing the readouts of temperature sensors which are integrated in each sensor head. Figure 4 shows the estimated temperature difference for all images of a typical UltraCamX test flight. At the beginning of the flight the temperature difference with respect to the camera calibration is constant at -3.8°C. When the flight at 3500 AGL starts (image number 405), air temperature decreases and temperature difference *dC* increases accordingly.

In Figure 5 the actual temperature readout of a temperature sensor is plotted for the same flight. Taking into account that the calibration temperature is about 38 °C this corresponds very well to the estimated temperature (measured temperature equals temperature at calibration time plus *dC*). This documents the correct function of the TDM correction model.

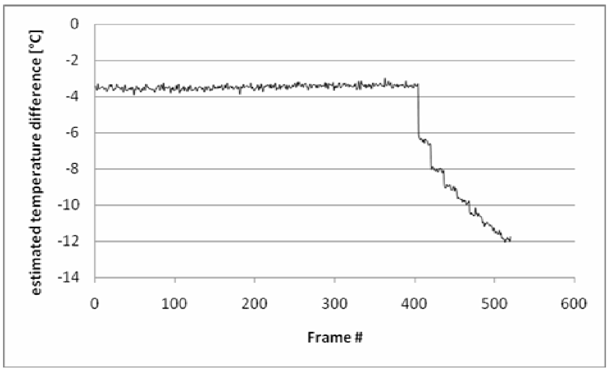

Fig 4: Temperature difference estimated by TDM

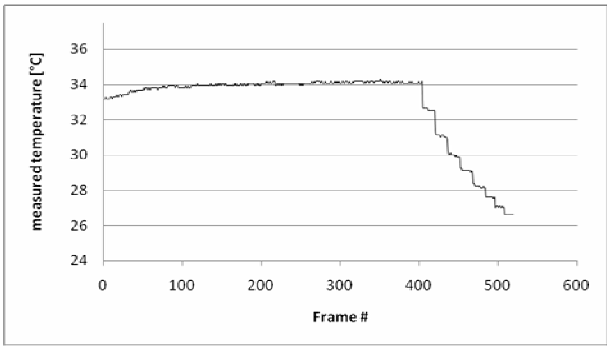

Fig 5: Readout of the temperature sensor during test flight.

Estimated TDM corrections are taken into account in the final stitching process. Hence errors introduced by temperature differences between camera calibration and flying conditions are removed. This can also be verified from the stitching scales depicted in Figures 6 and 7. These scales are expected to be close to 1.0 after TDM corrections have been successfully applied.

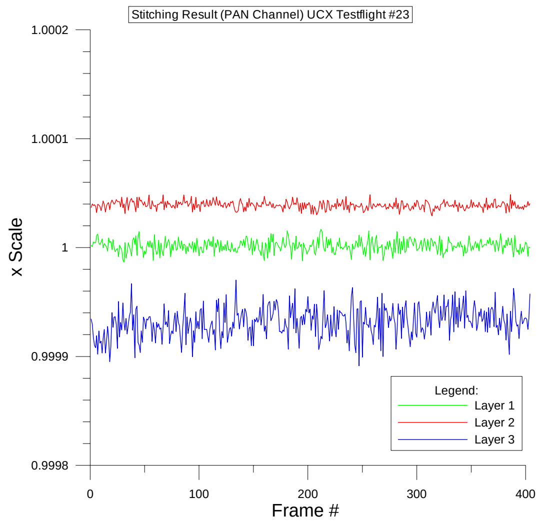

Fig 6: Stitching scales for the PAN channel (x component)

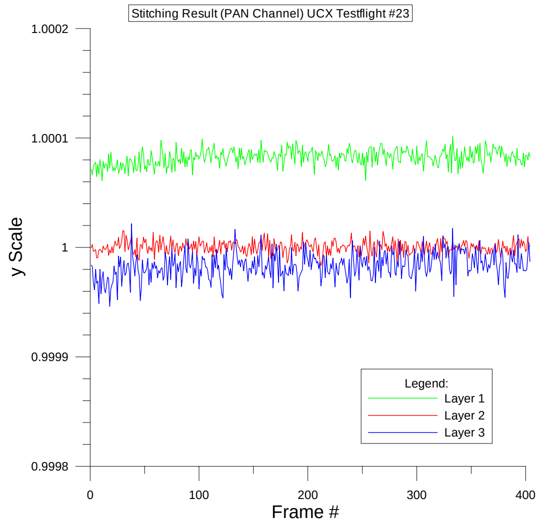

Fig 7: Stitching scales for the PAN channel (y component)

4. AUTOMATED AERIAL TRIANGULATION

After the post-processing an automated aero-triangulation (AAT) is performed for both flying heights using MatchAT from Inpho Stuttgart. The initial block setup is done by a semiautomatic workflow using the GPS navigation solutions. These WGS84 coordinates are part of the exposure annotation data (EAD), which are automatically written into the Lvl02 data structure during image post-processing. The advantage of using such approximate coordinates lies in the faster block setup – there is no need of waiting for post-processed GPS/INS data. This data is later used during the BINGO analysis.

For the aero-triangulation Lvl03 images are used, which are rotated 90 degrees counter clockwise, so that the x-axis is pointing into flight direction. This step is necessary since BINGO relies on this coordinate system definition.

Panchromatic images are used for the aero-triangulation due to faster processing. Another step before starting the aero-triangulation is the processing of image pyramids. From our experience it is sufficient to apply a 95% jpeg compression during the processing – this reduces the required storage space by about 50% without affecting the image quality significantly.

The camera definition in MatchAT is done by applying the PPA values which are stated in the camera calibration report. Image height and width (14430*9420 pixel) and the pixel size (7.2µm) have to be entered to complete the camera setup.

Fig. 8: Ground control point measured in MatchAT

The statistical output of MatchAT allows for a first geometric analysis. Characteristic precision values of UltraCamX test flight projects are summarized as follows:

- The precision of the manual GCP measurements is 0.2 pixel in the image plane.
- The automatic measurement of tie points has a precision of better than 0.15 pixel.
- Regarding the pixel size of 7.2µm the overall quality of the image coordinate measurements is about 1µm.

These values represent the capability of MatchAT's feature based matcher (FBM) and least squares matcher (LSM) to measure homologous at a very high level of precision. This comes along with the good radiometry of the images.

In the next step BINGO files are exported from the MatchAT projects. BINGO offers the opportunity to introduce camera specific parameters for self calibration. The results of this analysis are part of the next chapter.

5. ANALYSIS OF TEST FLIGHTS RESULTS

The bundle adjustment is performed using BINGO (GIP, Aalen). Additional parameters (ADPA) can be applied for camera self-calibration. BINGO supports traditional radial symmetric distortion parameters as well as new UltraCamX specific parameter sets. The latter correspond to the positioning (translation, rotation) and scaling of the nine images regions from which the panchromatic image is being composed.

With this comprehensive set of additional parameters small systematic image defects, which may still remain after the image post-processing, can be separated from stochastic image errors. Each UltraCamX test flight has been processed using three times using different sets of additional parameters:

1. Without any additional parameters (0 ADPA)
2. Using radial-symmetric parameters (2 ADPA)
3. Using radial-symmetric parameters and UltraCamX specific parameters (23 ADPA)

BINGO allows for a graphical and numerical presentation of the influences of those parameters. In the following the influences of the additional parameters onto the image geometry are described.

5.1 Enhancing the image geometry by self-calibration

The result of a bundle adjustment without additional parameters (Figure 9) shows a small remaining radial symmetric distortion which is eliminated by the usage of the according parameters. The maximal remaining image residuals are reduced from 3.4µm (without ADPA) to 1.2µm. The effect of additional camera specific parameters on the other hand is very small and can be neglected compared to the effect of the radial-symmetric parameters.

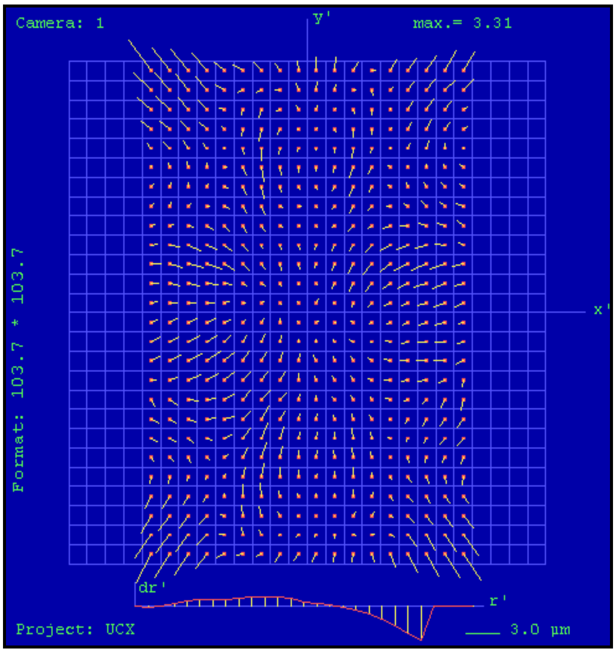

Fig. 9: Image residuals without additional parameters

Comparing the triangulations from different test flights, the high effectiveness of the radial-symmetric parameters has been verified. Figure 11 shows the radial-symmetric distortion for different test flights (AGL 1400m). The averaged radial distortion curve has a maximal value of 3.2µm. Maximum values differ about 0.5µm when comparing the individual flights.

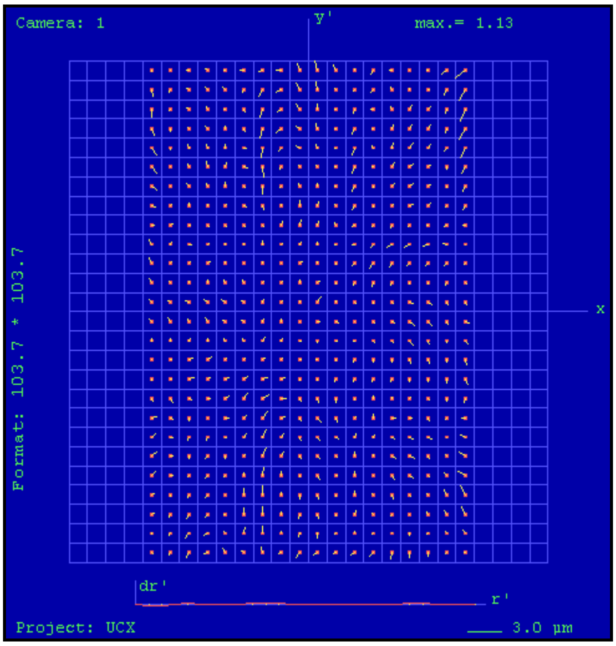

Fig. 10: Image residuals using radial distortion parameters

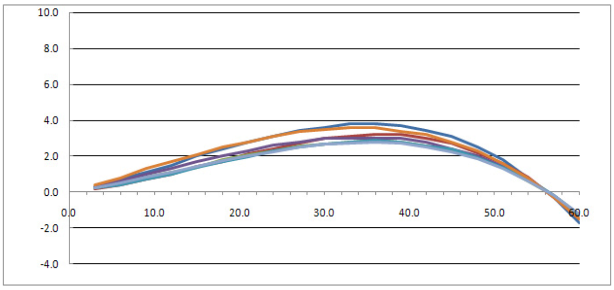

Fig 11: Radial symmetric distortion derived from various UltraCamX test flights.

For the second flying height (3500m AGL) the maximal radial symmetric distortion value is approximately 4.5µm. Since the difference between the distortion curves is very small and this is also verified from customer production flights, an average distortion of 3.2µm is going to be accounted for during image post-processing in the future. This will be done by integrating the averaged distortion curve into the calibration files of each delivered camera system.

For different flying heights the deviation from the averaged radial symmetric distortion curve reaches 1.9µm for the maximal value. Thus the production of widely distortion free images should be possible without aero-triangulation and self-calibration in the bundle adjustment.

5.2 Results of the UltraCamX test flights

Table 1 shows the relevant precision values of those UltraCamX, which were flown on the test area at Gleisdorf. The averaged radial distortion, which was described in the last section, is already taken into account. Differences between the flying heights indicate that atmospheric influences contribute to the distortion. Since the results of several UltraCamX testflights are shown, the standard deviation of the data series is given as well. Altogether, low sigma_0 values show the high quality level of the measurements.

		Sigma_0	**remaining image errors [µm]**	**radial-symmetric distortion [µm]**	**# Flights**
GSD 10 cm	Mean	0.87	0.87	0.50	40
	Std.Dev.	±0.11	±0.25	±0.27	
	Max	1.5	1.6	1.1	
GSD 25 cm	Mean	1.04	1.28	1.17	14
	Std.Dev.	±0.18	±0.31	±0.55	
	Max	1.8	1.7	1.9	

Table 1: Precision values from UltraCamX test flights

		Checkpoint residuals			**# Flights**
		X[cm]	Y[cm]	Z[cm]	
GSD 10 cm	Mean	3.3	3.7	4.8	20
	Std.Dev.	±0.82	±0.96	±0.53	
	Max	6.1	6.7	5.9	
GSD 25 cm	Mean	5.6	6.2	9.4	14
	Std.Dev.	±1.70	±1.79	±1.79	
	Max	8.7	9.7	12.1	

Table 2: Checkpoint residuals from UltraCamX test flights

When planning the test site it was attached importance on to an even distribution and a large quantity of ground control points. During the geometric analysis a considerable number of GCPs can thus be introduced as independent checkpoints in order to determine the absolute precision.

Table 2 shows the average estimated objectpoint precision and the checkpoint residuals of the UltraCamX test flights. Five ground control points (four in the edges – one in the middle) were used, the remaining points were introduced as independent check points. In addition to the average values the standard deviation and the maximal error is given in order to determine the quality of each delivered camera. Furthermore a difference between the two flying heights was made.

The low checkpoint residuals are proofing the high geometric quality of the UltraCamX camera system. A height precision of 0.035‰ (1400m AGL) and 0.03‰ (3500m AGL) has been determined. In Figure 12, checkpoint residuals are plotted in the above stated checkpoint / GCP configuration for the flying height of 1400m AGL. The absolute height precision is about half of a pixel and the positioning error is a quarter of a pixel, respectively. These precision values are valid for all of the analyzed cameras.

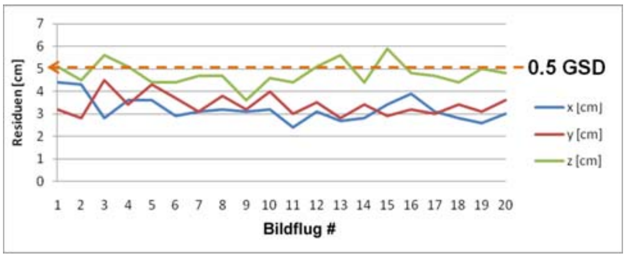

Fig. 12: Checkpoint residuals for GSD 10cm

For the flying height of 3500m AGL the checkpoint residuals are even better, as shown in Figure 13. A positioning precision of a quarter pixel and a height precision below half of a pixel is reached.

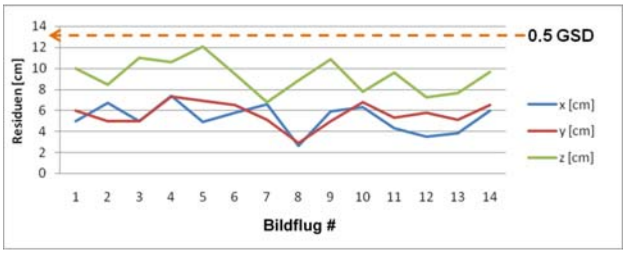

Fig. 13: Checkpoint residuals for GSD 25cm

6. CONCLUSIONS AND OUTLOOK

The geometric analysis of UltraCamX test flights showed that the quality of the temperature correction model and the applied traditional radial-symmetric parameters have a positive effect on the image geometry. Especially the precision at the checkpoints of 0,035‰ of the flying height shows the geometric quality of the UltraCamX. The temperature correction model described is implemented into the proprietary image processing software since 2006.

The geometric quality derived from the UltraCamX test flights was ascertained when analyzing various production flights. In the context of the Microsoft Virtual Earth Initiative the UltraCamX is being used successfully for the acquisition of aerial image data. The images are used for the fully automated 3D-reconstruction of objects in cities. The advantages of a digital camera, especially simultaneous capturing of RGB and CIR images as well as the possibility of a high forward overlap are a prerequisite for such applications.

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