COMPLETE PHOTOGRAMMETRIC SYSTEM CALIBRATION AND EVALUATION IN THE SJÖKULLA TEST FIELD – CASE STUDY WITH DMC

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ABSTRACT:

In the future field calibration and testing will be fundamental parts of photogrammetric production lines. The complete field calibration/testing concerns geometric, spatial, radiometric and spectral properties of the systems, and it is a crucial supplement to the laboratory calibration. In this article a method for complete calibration/testing of digital photogrammetric sensors, based on the Sjökulla test field of Finnish Geodetic Institute, is briefly described and its use is demonstrated with digital large format photogrammetric camera DMC. The tested DMC proved to be a high quality photogrammetric sensor. However, the flight testing revealed some parts of the system and processing, which could be further improved to obtain even higher image quality.

1. INTRODUCTION

Optimal utilization of the latest technical advancements makes the field calibration and testing of photogrammetric systems crucial. The most important innovations are the direct georeferencing techniques and the high radiometric quality of the digital photogrammetric sensors. It is obvious that the calibration should go beyond the geometric properties. Cramer (2004) has recently discussed the calibration issue.

The Finnish Geodetic Institute (FGI) has maintained a versatile permanent photogrammetric test field in Sjökulla since 1994 (Kuittinen et al. 1994). In the past the Sjökulla test field and transportable test figures have been used for the calibration and testing of analogue camera systems and direct georeferencing systems. Recently digital photogrammetric cameras, including three leading large format digital systems and a medium format DSS-system have been tested in Sjökulla. Results of previous tests were given by Ahokas et al. (2000), Honkavaara et al. (2003, 2005, 2006) and Markelin et al. (2005, 2006).

In this presentation we will shortly describe an approach for the calibration and testing of digital photogrammetric systems. We will demonstrate the use of this approach with DMC digital large format camera.

2. MATERIALS AND METHODS

2.1 Method for complete system calibration

The complete digital photogrammetric system calibration should include geometric, spatial, spectral and radiometric parts. The Sjökulla test field contains permanent ground control points (GCPs), test-bar targets and grey scale, which can be used in a wide scale range (GSD 5-50 cm). Important portable extensions to the permanent targets are 8-step grey scale and a Siemens star. Special measurement equipment, e.g. portable field spectrogoniometer (Peltoniemi et al. 2005), complements the test field. The spectral calibration is not possible in Sjökulla at the moment. Aerial photo of the image quality test site is shown in Figure 1. In the following only short descriptions of the testing methods are given. More details of the test targets and methods have been given by Kuittinen et al. (1994), Ahokas et al. (2000), Honkavaara et al. (2003, 2005, 2006) and Markelin et al. (2005, 2006).

For the geometric calibration the Sjökulla test site contains targeted benchmarks for large, medium and small-scale applications. The geometric calibration and testing is performed by means of a bundle block adjustment. The results of the geometric calibration are the system calibration parameters (lever arms, boresight), camera interior orientation parameters, lens distortions, plots of the systematic image errors, and results of the point determination and back projection accuracy evaluation (Honkavaara et al. 2006).

The spatial resolution is evaluated using test bar targets and Siemens star. From the bar targets the resolving power values and widths of the thinnest resolvable lines in field are evaluated (Ahokas et al. 2000, Honkavaara et al. 2005). Siemens star is used for the MTF evaluation (Becker et al. 2005). Spatial resolution is evaluated in various locations of the field of view (FOV) of the sensor in the flight and cross-flight directions.

The radiometric quality is evaluated using a calibrated 8-step grey scale. The dynamic range, linearity and noise of the sensor are measured. In order to accurately perform the radiometric calibration/testing, knowledge of BRDFs (Bidirectional Reflectance Distribution Function) of the reference reflectance targets is necessary. BRDFs of the FGI's grey scale were measured in laboratory using the portable field goniospectrometer of FGI (Peltoniemi et al. 2005, Markelin et al. 2006). In the most accurate applications BRDF measurements are performed simultaneously to the test flights in field.

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Figure 1. Overview of Sjökulla test site. The test figures used in this study are: 1) permanent dense spatial resolution test bar targets, 2) transportable grey scale with 8 steps and 3) transportable Siemens star. Photo by Meixner.

2.2 DMC test flights

The DMC test flights were performed in Sjökulla during two days in co-operation with the National Land Survey of Finland (NLS) in the beginning of September 2005. Analogue reference imagery was collected simultaneously by RC20 (the exposures were not synchronised). The cameras were installed in the OH-ACN aircraft of NLS (Rockwell Turbo Commander 690A turbo twin propeller aircraft with a pressurised cabin and two camera holes). Furthermore, parallel to the test-flights, BRDF measurements of the reflectance targets were performed in field by a goniospectrometer.

The DMC was mounted on T-AS gyro stabilised suspension mount. Technical details of DMC are given by Intergraph (2006). No GPS or GPS/IMU data was collected. Flying heights were 500 m, 800 m, 2500 m and 5000 m, giving GSDs 5 cm, 8 cm, 25 cm and 50 cm. DMC Post processing software (Version 4.5) was used for the calculation of the final panchromatic and pan-sharpened/no-pan-sharpened CIR and RGB images. Non-linear tonal transformations were not performed for the images, which were used in radiometric evaluations. In this article results from flights with 5 cm GSD (d1_g5) and 8 cm GSD (d1_g8a, d1_g8b) are given (see details in Table 1, Figure 2).

Reference analog images were collected by RC20 camera of NLS using panchromatic and colour films. Wide-angle optic (150 mm) was used, which provides approximately the same image width in ground as DMC. The camera mount was PAV 11A-E (not gyro stabilised) and FMC was applied. The films were scanned by Leica Geosystems DSW 600 scanner with 10 and 15 µm pixel size.

2.3 Methods

2.3.1 Geometric quality evaluation: The image measurements for block adjustments were performed using the ISAT software of Intergraph. Bock adjustments were performed by the inBlock software of Inpho. The size of the test field was 1 km x 1 km and it contained approx. 40 targeted benchmarks.

Principal point coordinates and common image deformation parameters (physical image deformations: radial and tangential distortion, affinity and shear, Ebner's parameters and Brown's parameters) were determined in the system calibration. Full blocks and full GCPs were used (Figure 2).

Point determination accuracy was evaluated selecting appropriate sub-blocks from the full blocks (Figure 2):

- d1_g5: 4 strips (p=q=60%) and 2 strips (p=60%, q=20%)
- d1_g8a and d1_g8b: 4 strips (p=60%, q=80%) and 2 strips (p=60%, q=40%)

Of 40 targeted benchmarks 12 were used as GCPs and the rest were used as checkpoints. Theoretical accuracy (RMS value of standard deviations of point unknowns obtained from the block adjustment) and empirical accuracy (RMSE of differences in the checkpoints) were evaluated.

Table 1. Test blocks.

Block	d1_g5	d1_g8a	d1_g8b
Date	1.9.2005	1.9.2005	2.9.2005
GSD (cm)	5	8	8
Optic (mm)	120	120	120
Flying height (m)	500	800	800
Scale	1:4167	1:6667	1: 6667
Swath width (m)	691	1106	1106
Overlaps (%)	p=q=60	p=80, q=60	p=80, q=60
Strips parallel cross	6 2	4 3	4 -
Photo/strip parallel cross	3 or 6 7	5 4	4 -

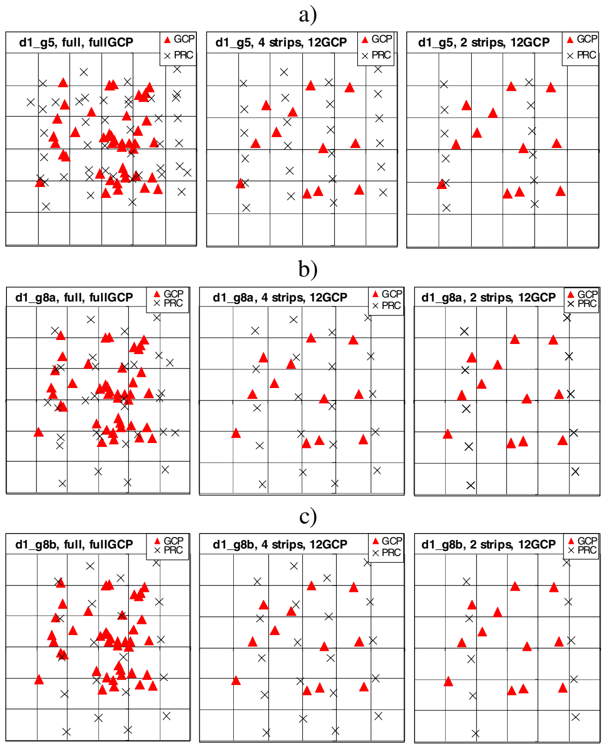


Figure 2. Block structures and GCP configurations at Sjökulla large-scale test-field, approx. 40 GCPs. a) d1_g5, b) d1_g8a and c) d1_g8c. Left: full block, full GCPs; Center: 4 strips, 12 GCPs; Right: 2 strips, 12 GCPs

Table 2. Statistics of test field calibration of DMC. RMSE of image residuals in x- and y-directions, principal point corrections and standard deviations, maximum local systematic deformation.

Block	σ_{ima_resi}[µm]		PP [µm]				Max Syst [µm]
			Correction		Stdev		
	x	y	x0	y0	x0	y0	
d1_g5	2.3	2.2	-5.0	-77.9	5.3	6.2	4.0
d1_g8a	2.8	2.7	-11.2	-54.8	5.0	5.3	6.5
d1_g8b	2.4	2.2	7.1	-69.1	5.4	5.9	6.7

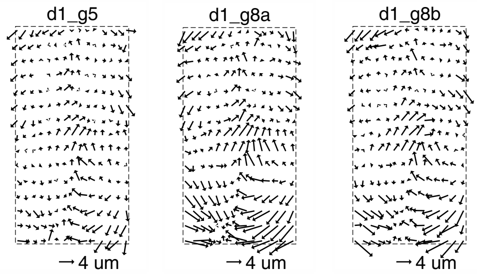


Figure 3. Systematic of image residuals.

2.3.2 Spatial resolution evaluation: Resolving power was evaluated from the bar target figures using RESOL-software (Ahokas et al. 2000, Honkavaara et al. 2005). For each flight averages of the RP-values and the thinnest resolvable line widths in ground were used as quality indicators. MTFs were evaluated from Siemens star both in FGI and ifp Stuttgart based on Becker et al. (2005).

2.3.3 Radiometric quality: Linearity and dynamic range of the sensor was measured from transportable 8-step grey scale using methods described by Markelin et al. (2005, 2006).

3. RESULTS AND DISCUSSION

3.1 Geometric testing and calibration

RMSEs of image residuals in x- and y-direction are given in Table 2 (full block, all GCPs, no additional parameters). The RMSEs were between 2.2 and 2.8 µm.

The local systematic deformations of the images were evaluated by calculating averages of the image residuals in 15 x 15 grid. It should be realized that the real systematic is larger than the systematic obtained from adjusted residuals. Results are shown in Figure 3. The 4-head structure of DMC can clearly be detected in the residuals. The maximum systematic errors were 4.0-6.7 µm (Table 2). The systematic errors were larger on blocks with 8 cm GSD. This is most likely caused by the stronger block geometry (80% side lap), which reveals the systematic errors more efficiently. Systematic appeared to be quite stable.

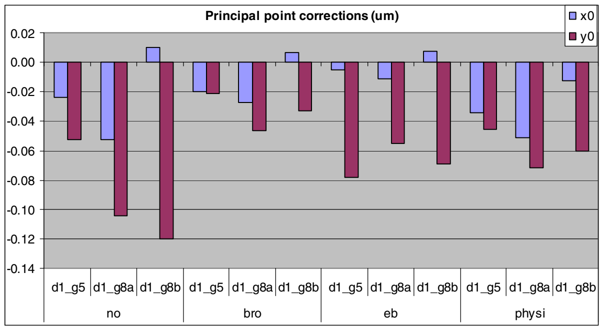
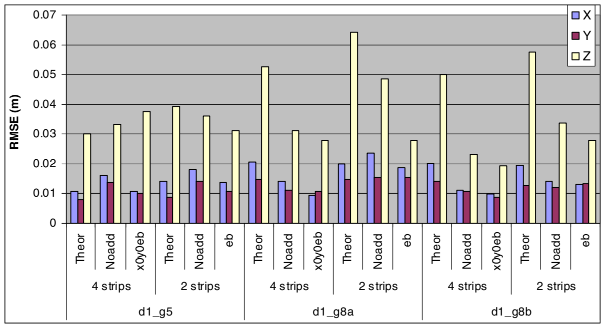
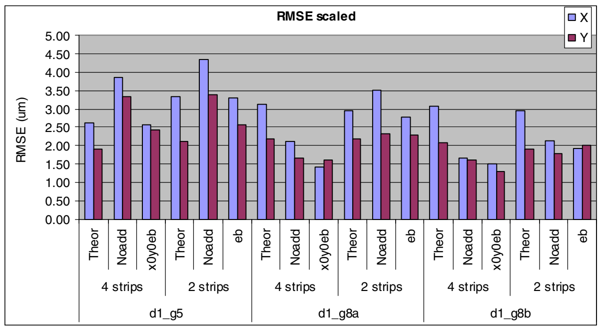


Figure 4. Corrections for principal point without additional parameters (no) with Brown's (bro), Ebner's (eb) and physical (physic) parameters.

a)



b)



c)

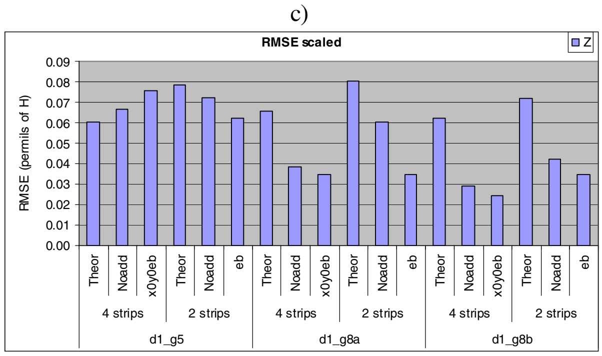
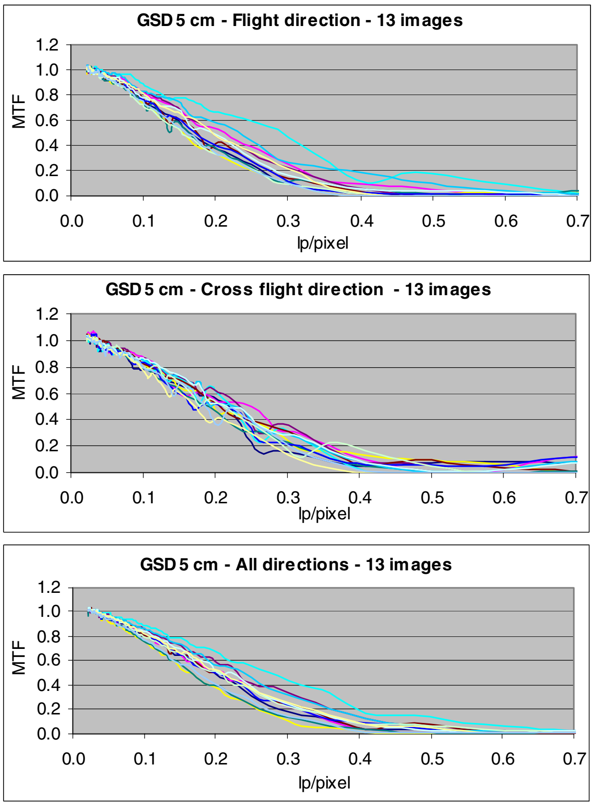


Figure 5. Point determination accuracy. a) RMSEs in object, b) horizontal RMSE scaled to image, c) height RMSE as ‰ of object distance.

a)



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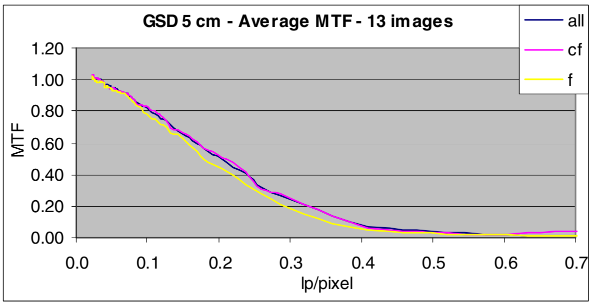

Figure 6. a) MTF of 13 images with 5 cm GSD in flight firection (top), cross flight direction (central) and the whole star (bottom), b) Average MTF of the 5 cm flight (f=flight direction, cf=cross flight direction).

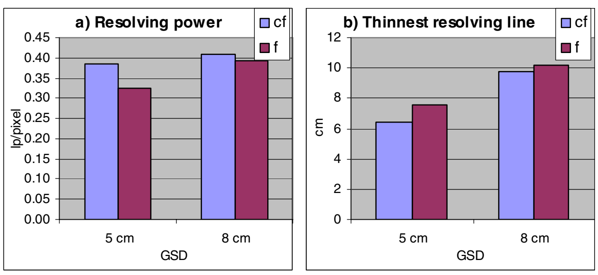

Figure 7. Determination of the spatial resolution from bar targets (f=flight direction, cf=cross flight direction). a) Resolving power and b) thinnest resolving line.

It is clear that the single head additional parameters do not optimally model the systematic deformations shown in Figure 3. Nevertheless, the standard additional parameters were estimated in adjustments. Typically many of the additional parameters were significant. As an example principal point corrections are given (Figure 4, Table 2). The correction was larger in y-direction (perpendicular to flight direction) than in x-direction. The selected additional parameters model affects the principal point corrections due to the correlations. With Ebner's parameters the correction in y-direction was -55 to -78 µm and in x-direction –18 to 7 µm.

Accuracy of point determination is shown in Figure 5. Three accuracy estimates are shown: theoretical accuracy of the point unknowns (Theor), empirical accuracy without additional parameters (Noadd) and empirical accuracy with principal point corrections and Ebner's additional parameters (x0y0, eb). The best accuracy in object was better than 10 mm in horizontal coordinates and 20 mm height, which is close to the estimated accuracy of the GCPs. The horizontal RMSE (scaled to image) was 1.5–4.5 µm and the height RMSE was 0.025-0.075‰ of the object distance. The block with 5 cm GSD gave worse accuracy than the blocks with 8 cm GSD and the accuracy of the block d1_8a was slightly worse than accuracy of the block d1_8b; these issues will be further studied. As expected, the use of weaker block geometry (2 strips) deteriorated the height accuracy and with 2 strips the additional parameters improved the height accuracy. The use of less GCPs might reduce the accuracy as well.

According to Dörstel (2003) the expected accuracy of DMC blocks is in horizontal coordinates 5 µm in image and in height 0.05‰ of the object distance. The obtained values were on the expected level. It is possible that the use of a more adequate additional parameter model could improve the accuracy further. The accuracy was mostly on the same level as the accuracy of analogue cameras. The further studies of the point determination accuracy will concern the effect of GCP distribution, evaluation of the smaller scale blocks and the above questions.

3.2 Spatial resolution

Results of MTF measurements from Siemens star for block d1_g5 are given in Figure 6. The MTF was evaluated for the flight direction (f), for cross flight direction (cf) and for the entire Siemens star (all). MTF curves calculated for each image were quite noisy (Figure 6a) but the noise was smoothed in the average curves (Figure 6b). The results indicated that the resolution was worse in the flying direction than in the cross flight direction, which is probably caused by image motion in flying direction. The studies of MTF are still going on.

The average smallest resolvable lines were for the block d1_g5 1.5xGSD in the flight direction and 1.3xGSD in the cross flight direction (Figure 7b). For the block d1_g8a the average smallest lines were 1.3xGSD in the flight direction and 1.2xGSD in the cross-flight direction (Figure 7b). Resolving power was between 27 and 34 lp/mm (0.32 to 0.41 lp/pixel), while the best possible value for the 12 µm pixel size is 42 lp/mm (0.5 lp/pixel) (Figure 7a).

3.3 Radiometry

Results of the radiometric quality evaluation for the block d1_g5 are shown in Figure 8. Average digital numbers of the steps of the grey scale are shown as the function of the laboratory measured reflectance for panchromatic and for non pan-sharpened red, green, blue and NIR-channels. Green band appeared to have the worst performance. It typically saturated soon after 65% reflectance and in some cases even with smaller than 65% reflectance values. Other channels were typically saturated somewhere between 65% and 90% reflectance. Linearity of the sensor appeared to be good in the area, which was not saturated. One reason for the variations between the various images was BRDF-effects.

4. CONCLUSIONS

Field calibration and testing must be parts of the photogrammetric production lines in the future. The use of the permanent Sjökulla test field for the geometric, spatial and radiometric photogrammetric system calibration has been demonstrated in this article using data from DMC test fights.

The preliminary results proved that the tested DMC was a high performance digital large format sensor. Results indicated that the geometric, resolution and radiometric performance of the sensor could be improved even further. More detailed results will be published later.

Building and maintenance of accurate reference targets and execution of rigorous sensor tests are expensive. Studies of the test flight data collected in Sjökulla will give information how to optimize the testing procedures.

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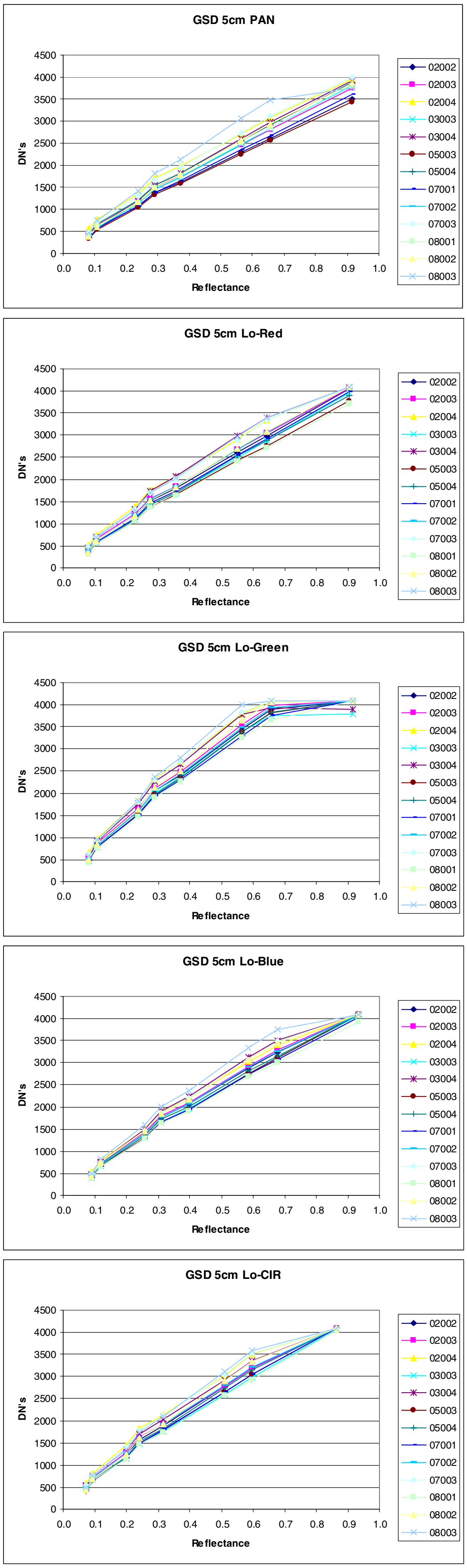

Figure 8. Grey scale measurements on DMC images, one line per image. Channels from top to bottom: PAN, red, green, blue, CIR (color channels not PAN sharpened).

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