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The DGPF-Test on Digital Airborne Camera Evaluation – Overview and Test Design

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Summary: This paper focuses on general remarks on the test of the German Society of Photogrammetry, Remote Sensing and Geoinformation (DGPF) on Digital Airborne Camera Evaluation. It should be seen as an introductory paper which explains the test bed itself, the available reference and test data sets and the overall organization and structure of the data evaluation. The more detailed results are published in separate papers, which are also part of this journal issue.

Zusammenfassung: *Der DGPF-Test zur Evaluation digitaler Luftbildkameras – Überblick und Testdesign.* Dieser Artikel konzentriert sich auf grundsätzliche Anmerkungen zum Test von digitalen photogrammetrischen Luftbildkamerasystemen, durchgeführt von der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation (DGPF). Der Beitrag soll einen Überblick über die Rahmenbedingungen des Tests geben, die verfügbaren Referenz- und Testdaten vorstellen und die Struktur und Organisation der Datenauswertung erläutern. Die detaillierten Ergebnisse der Auswertungen werden in separaten Beiträgen vorgestellt, die ebenfalls Bestandteil dieser Ausgabe der Zeitschrift sind.

1 Introduction

Despite the fact, that digital airborne photogrammetric imaging is already widely used for operational projects and sales numbers of digital airborne cameras are much higher than originally expected from the manufacturers' point of view, comprehensive and independent empirical tests on system performance and quality of photogrammetric products based on digital airborne images are only partially available. Tests published in PASSINI & JACOBSEN (2008) or CRAMER (2007) could be mentioned, mainly focussing on the geometric performance of the systems and not covering the latest generation of sensor development. Investigations on the radiometric systems potential and applications can be found in MARTÍNEZ et al. (2007) and HONKAVAARA et al. (2009). Some of these tests also used hyperspectral sensors flown parallel to the digital camera. They are of high importance to evaluate the use of these new imaging sensors in remote sensing applications. Even though such tests already proved the high potential of digital airborne sensors, at the end of 2007 the German Society of Photogrammetry, Remote Sensing and Geoinformation (DGPF) decided to run a separate and independent test on the evaluation of digital photogrammetric camera systems – not only to confirm results of the earlier tests but also to check the latest generation of digital camera systems and the products derived from them. Not only the camera but the whole process chain is covered and evaluated, as necessary for operational applications. Nevertheless, with digital systems the link to the processing software is much tighter. Many systems do need special software to take care of the individual sensor designs (for example for sensor related image post-processing like virtual image formation or line-scanner image rectification).

The individual and heterogeneous sensor design is another reason why empirical tests in controlled and well established test sites raise in importance and will become inherent part of future system certification and validation processes. Current calibration of photogrammetric sensors already has changed – for example, looking on the role of calibration certificates from laboratory calibration: The classical calibration of analogue mapping cameras is certified by official metrology organizations, thus the calibration protocol automatically serves as the official certificate. It is internationally accepted through common agreements and typically requested as evidence of correct system functioning for tenders. For the new digital sensors, calibration processes are designed and performed by the manufacturers themselves, but not yet certified by independent metrology institutions. Some parts of the calibration are already exclusively done from real flight data using in-situ calibration approaches.

Thus, empirical tests in controlled environments are not only used for quality assessment and system or product validation, they will also be of increased importance in system calibration already, which again underlines the need for current and future test site evaluations.

Today's situation in digital airborne camera evaluation thus underlines the need for empirical and independent tests where in the ideal case all photogrammetric cameras used in practice are involved and all are flown in comparable flight conditions. These tests have to be comprehensive, namely, looking into various aspects of the sensor system (geometry, radiometry) and also cover the product generation domain as well as the associated process chain.

For this purpose several flight campaigns were carried out in the framework of this DGPF camera evaluation test using the Vaihingen/Enz photogrammetric test site. This site is the most used airborne test site for photogrammetric applications in Germany and one of the three to four well established and manufacturer independent photogrammetric airborne sites available in Europe (CRAMER 2005). The test site is maintained by the Institute for Photogrammetry (ifp), Universität Stuttgart – thus, the ifp also served as Pilot Centre during the test, responsible for the project coordination under the umbrella of the DGPF, the request of data from the manufacturers and the later distribution to the interested parties. The Pilot Centre also prepared reference orientations which were commonly used to derive the sensor products (CRAMER & HAALA 2009). All data was made available for all types of institutions ranging from science, mapping authorities, photogrammetric companies to sensor providers.

The DGPF test can be seen as a benchmark to compare airborne sensor performance. This is often requested from the photogrammetric community and actually was one of the user driven motivations of the test. Still, the main objective of this test is not to directly compare different sensors but to evaluate the sensor specific strengths and weaknesses, which are of relevance when choosing a sensor for specific applications. Since all findings obtained in this test are based on the results of the Vaihingen/Enz test flights only, they have to be confirmed by tests in other sites.

In the next section of this paper the test field Vaihingen/Enz and the available reference data from ground and airborne flights are presented. In section 3 the test data, as flown by the different camera systems is described. These two sections are of importance for the other reports on this project in this journal issue. Section 2 and 3 already illustrate many of the boundary conditions during data acquisition, which are of impact for further processing and results. Finally, section 4 briefly describes the organization of the expert network during data evaluation.

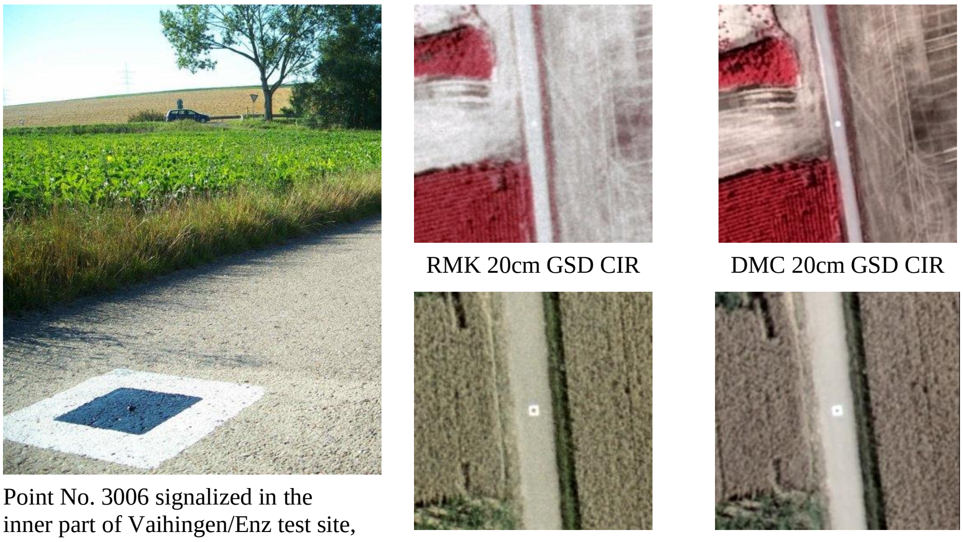
2 Reference test data

2.1 Permanent test field Vaihingen/Enz

The airborne data was acquired in the Vaihingen/Enz test area. This site covers about 7.4 x 4.7km² and is located 25km north-west of Stuttgart, Germany. Some 200 signalized points are available, marked permanently with white painted squares (60 x 60cm²). The targets are regularly distributed in the test area. Higher resolution imagery is proposed to be taken in the inner part of the Vaihingen/Enz test site, where additional 30 x 30cm² black squares are painted in the centre of each of the larger white targets to allow for the precise detection of point centres in the images (Fig. 1). The higher resolution flights with ground sampling distance (GSD) of 8cm presented later were restricted to this part of the test field only.

Assuming flights with a GSD of 20cm the target size in image space will be in the range of (at least) 3 x 3pixel, which is sufficient for manual measurements. Effectively, due to blooming effects the imaged points appear much larger (about 6 x 6pixel for 20cm GSD). Still, measurements of image points have shown that especially for scanned analogue images, the clear identification of signals caused problems for some points in lower contrast areas and for operators not familiar with the test field and point locations. Fig. 1 exemplarily shows a signalized point located in the inner part of the test site and how this point is imaged in analogue RMK and digital DMC images. These two systems were flown simultaneously with an airplane equipped for two cameras (almost parallel image recording from the same flying heights and in same environmental conditions). Thus the images of the two systems can be compared directly. Both, the images from 20cm GSD and 8cm GSD are shown. Modest contrast enhancement was applied to the given image samples. The differences in the quality of point identification are obvious, mainly for the 20cm GSD image samples. Here the superior radiometric image quality of DMC and digital cameras in general is obvious. For the 8cm GSD flight the target is clearly identified in both data sets. One should mention that in this case the RMK 8cm GSD images seem to be sharper than the large-format RGB DMC 8cm GSD images, which is not the case for the pan-chromatic virtual DMC image. The geometric resolution of different sensors and their image products is currently quantified from the analysis of the Siemens star resolution target (see Fig. 2).

Correct identification and measuring of the signalized targets during manual image mensuration is essential for highly accurate results. In JACOBSEN et al. (2010) manually obtained image coordinates provided by different operators from different institutions are compared and analysed to estimate the variance of manual image point observations.



Point No. 3006 signalized in the inner part of Vaihingen/Enz test site, painted on paved country side road.

RMK 20cm GSD CIR

DMC 20cm GSD CIR

RMK 8cm GSD RGB

DMC 8cm GSD RGB

Fig. 1: Signalized point in the Vaihingen/Enz test site and the corresponding image points in simultaneously recorded scanned analogue RMK and digital DMC images.

The object coordinates of the signalized points were determined from static differential phase GPS base line observations in ETRS89/UTM coordinates (using ellipsoidal heights). This coordinate frame is also used in later evaluations. The obtained accuracy of the object points (coordinate error) is in the range (Std.Dev.) of 1cm (horizontal) and 2cm (vertical). The accuracy was verified from repetitive base line measurements. It has to be kept in mind when the absolute quality of point determination (or surface model generation) from images is assessed from check point differences. Especially for the high resolution flights (8cm GSD) the absolute accuracy of signalized points is not sufficient to comprehensively serve as reference, as long as sub-pixel accuracy is expected. Assuming high image resolution (which typically comes together with high demands in accuracy) the accuracy of the reference points is thus not of superior quality. This in principle is a general problem which is created by the increasing need for highly resolved images with sub-decimeter resolutions. This automatically increases the demands on the quality of the reference data itself.

For the empirical processing of the test data object space coordinates of 111 signalized points were delivered to the test participants. Most participants used a sub-set of these as control points and the remaining ones as check points for absolute accuracy assessment. Besides, another 78 points were only made available with reduced accuracy, their full coordinate information stayed with the Pilot

Centre. In this way fully independent accuracy evaluation is possible, in order to cross-check results obtained from other participants.

System providers had access to 19 ground control points to check whether their data sets were consistent and comparable to other flights, before data was sent to the Pilot Centre for further dissemination. Apparently, some of the sensor providers used these reference points to already go into deeper analysis of the sensor data. Thus not all finally delivered data sets may fully reflect the standard quality (status of pre-processing) of data which is typically obtained in operational survey mission scenarios.

2.2 Geometric and radiometric resolution test site

In addition to the permanently signalized control points, the test field was amended with temporal targets for the estimation of geometric and radiometric sensor resolution. Fig. 2 shows geometric and radiometric test targets which were installed for each of the different flight days. The colour targets and different resolution test targets (Siemens star) can be seen. The large Siemens star is of 8m in diameter; all other targets are of 2 x 2m² in size. It should be mentioned that the relatively small colour targets were only sufficient for the higher resolution 8cm GSD flights. This was especially the case when the colour information was captured with coarser spatial resolution compared to panchromatic images as the case for the DMC and Ultracam-X frame based sensor systems. Additionally the colour targets suffered from strong directional reflection effects. This fact later prevented parts of the originally planned absolute radiometric sensor calibration (Schönermark 2010).

The relatively small resolution site is located in the inner part of test field Vaihingen/Enz and thus covered by both the 8cm GSD and 20cm GSD flights. Additionally, a separate north-south flight line (so-called radiometry flight line) was planned for each flying height, with these targets located in its centre, fulfilling a pre-condition for the later radiometric sensor analysis. Thus, this radiometric and geometric resolution test site was always flown in cross-pattern.

Parallel to the flights, spectrometer and sun photometer measurements were done on the ground to independently measure the spectral characteristic of natural and artificial targets and the optical thickness of the atmosphere. These reference measurements are essential for the later radiometric performance analyses (Schönermark 2010). Additional field surveys were carried out to map the land use in parts of the Vaihingen/Enz test site. (Waser et al. 2010).

Fig. 2: Vaihingen/Enz radiometric test field from the air (left) and ground team members performing spectrometer measurements parallel to sensor flights (right).

2.3 Reference data from airborne sensors

In addition to the previously described reference measurements on the ground additional reference data were recorded from separate sensor flights (see lower part of Tab. **1**). Two different hyper-spectral sensors were flown, namely the specim AISA+ and the DLR ROSIS system, both only covered parts of the test field. The AISA+ flight was done as a double-hole flight together with a DMC camera. Unfortunately, this valuable data has not yet been fully investigated in the performance evaluation tests (SCHÖNERMARK 2010).

In order to obtain dense reference data for the evaluation of photogrammetrically derived surface models an ALS50 LiDAR flight was done in August 2008 . In order to provide a sufficiently dense reference point distribution on the ground for the later evaluation of the very dense point clouds from image matching a LiDAR point density of 5 pts/m² was chosen.

The data from hyper-spectral and LiDAR reference flights was processed by the system providers and then delivered to the project participants via the Pilot Centre. In case of the ALS50 LiDAR data later analysis showed, that there was some potential to refine provided data at first. This issue is more deeply discussed in HAALA et al. (2010).

3 Digital camera test flights

The digital camera flights were flown at six different flight days during a 10 weeks time window from the beginning of July till the middle of September 2008 (Tab. 1). Originally a much shorter time period of only two weeks was planned for the photogrammetric data acquisition, which could not be realized due to weather conditions. Most sensors were flown in two different flying heights, resulting in two blocks with the previously defined different ground sampling distances 20cm GSD and 8cm GSD (nominal values). The 20cm GSD blocks covered the whole test area; the GSD 8cm blocks were limited to the centre part.

The 20cm GSD blocks were flown with a forward overlap of p=60%, whereas a higher forward overlap of p=80% was aimed at the 8cm GSD blocks. The side overlap between image strips was consistently defined with q=60%, all this agreed in the project definition phase. Due to the fixed test site extensions and different sensor formats slight adaptations of the block geometry were necessary (mainly influencing side overlap) which potentially influences the later comparison of sensor performance. Additionally, not all test data finally fulfilled the defined overlap requirements.

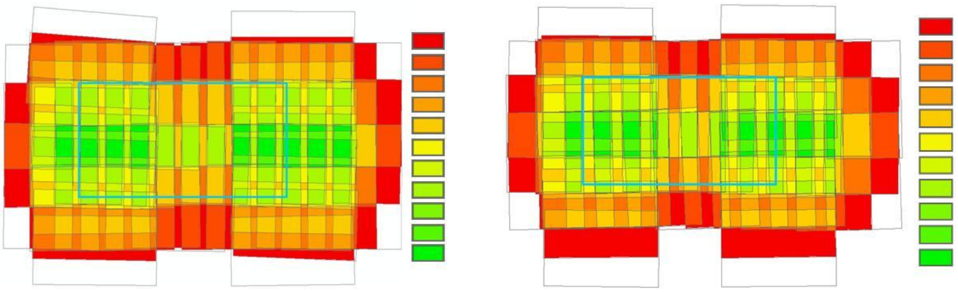
Some of the sensors were only flown in one flying height (namely the AIC-x1 and 3K-camera), other data sets were influenced by technical problems. This is why AIC-x4 images finally were not made available. One of the Quattro DigiCAM camera heads was slightly defocused during the flight. However, this did not affect the later aerial triangulation. The DMC and RMK-Top15 flights were done as true double-hole flights, where the flight trajectory was fixed to the DMC sensor geometry. Since analogue RMK images were scanned with 14µm resolution the requested 20cm GSD and 8cm GSD images are obtained. The Zeiss/ZI-Imaging scanners SCAI (20cm GSD, Kodak MS 1443 CIR film) and PhotoScan2001 (8cm GSD, Agfa X-100 CN film) were used to digitize the analogue RMK images. More detailed block configurations and flight parameters for RMK-Top15, DMC, Ultracam-X, Quattro DigiCAM and ADS40 can be seen in CRAMER (2009). More detailed additional information can also be found in the project web site (DGPF 2009, in German).

The overlap conditions for DMC and Ultracam-X blocks 20cm GSD and 8cm GSD are depicted in Fig. 3. Notice the different scaling of the legend colours. The red colour always depicts areas with 2 folded image overlap only, whereas the maximum overlap varies from 12 folded (for 20cm GSD blocks) to 30 folded images (for 8cm GSD Ultracam-X block). The DMC 8cm GSD block only has 14 folded overlap maximum. Even though there are slight differences in the side overlap parameters for the two 20cm GSD blocks, the overlap conditions are quite close to the pre-defined values. The larger differences for the 8cm GSD blocks are due to the much higher forward overlap (p=80%) for the Ultracam-X flight compared to 60% for the DMC block. This definitely impacts the geometric block layout and the quality of object points.

Tab. 1: Participating sensor systems and involved flying companies.

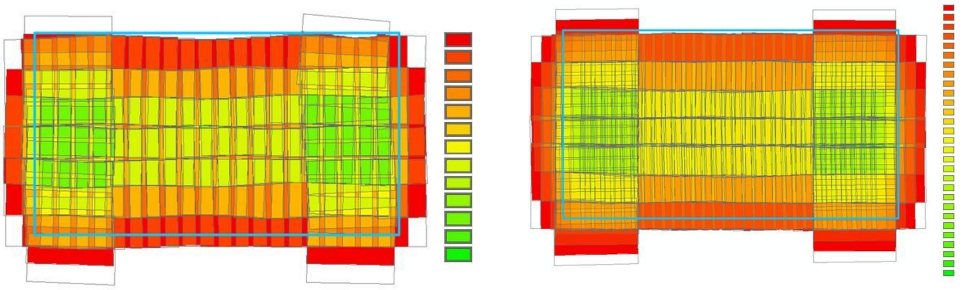
System	System provider / manufacturer	System flyer	Day(s) of flight	Remark
DMC	Intergraph/ZI	RWE Power	24.07.2008 & 06.08.2008	double-hole flight with RMK-Top15 8cm GSD with p=60%
ADS40, SH52	Leica Geosystems	Leica Geosystems	06.08.2008	
JAS-150	Jenaoptronik	RWE Power	09.09.2008	
Ultracam-X	Vexcel Imaging Graz	bsf Swissphoto	11.09.2008	
RMK-Top15	Intergraph/ZI	RWE Power	24.07.2008 & 06.08.2008	double-hole flight with DMC 8cm GSD with p=60%
Quattro Digi-CAM	IGI	Geoplana	06.08.2008	
AIC-x1	Rolleimetric	Alpha Luftbild	11.09.2008	only 8cm GSD, no cross strips
AIC-x4	Rolleimetric	Vulcan Air	19.09.2008	data not made available for project
DLR 3K-camera	DLR Munich	DLR Munich	15.07.2008	only 20cm GSD, no cross strips
AISA+ hyper-spectral	specim FH Anhalt	RWE Power	02.07.2008	double-hole flight with DMC
ROSIS hyper-spectral	DLR München	DLR Munich	15.07.2008	
ALS 50 LiDAR	Leica Geosystems	Leica Geosystems	21.08.2008	

As already described in other papers discussing the evaluation of the DGPF test flight data, the long flight period not only leads to strong changes in the sun illumination conditions (decrease in maximum sun angle) and vegetation (vegetation period from midsummer till early fall was covered, including the complete harvesting period), the weather changes and the quite in-stable weather conditions during this flight season were of real influence on the data acquisition. The originally defined conditions on cloud free sky and flights at maximum sun angle (during noon time) could not been realized in several flights. Concessions had to be made, especially with progressing flight season. Unfortunately, no direct link to official weather recordings could be established, nevertheless, cloud coverage has beenrecorded and documented on an hourly basis by a web cam located in Vaihingen/Enz city centre. Additionally, the sun photometer measurements recording the transmission of atmosphere also indicate the cloud coverage in that part of the test site, where the radiometric and geometric resolution test area is located (see Fig. 2 and SCHÖNERMARK (2010)). The weather situation is exemplarily shown by the web cam images for the flight day August 6 (Fig. 4). As can be seen from Tab. 1, DMC (with RMK in the same plane), Quattro DigiCAM and ADS40 were flown on that day. The DMC flight was performed in almost perfect cloud conditions from UTC 7:50h – 8:30h (only 8cm GSD was flown). The ADS40 and Quattro DigiCAM flights were partially done in parallel. As one can see, the cloud situation significantly changed during the data acquisition period from UTC 9:30h (start of Quattro DigiCAM flight) till UTC 12:00h (end of ADS40 image recording). This change in illumination directly influences the radiometric sensor performance and also has to be considered for automatic and manual image measurements. As described in SPRECKELS et al. (2010) different shadow conditions are also of impact on the manual stereoplotting.



DMC 20cm GSD block
(2 (dark red) – 12 folded overlap (dark green))

Ultracam-X 20cm GSD block
(2 (dark red) – 12 folded overlap (dark green))



DMC 8cm GSD block
(2 (dark red) – 14 folded overlap (dark green))

Ultracam-X 8cm GSD block
(2 (dark red) – 30 folded overlap (dark green))

Fig. 3: Block configurations / image overlap conditions (colour-coded) for DMC and Ultracam-X blocks.

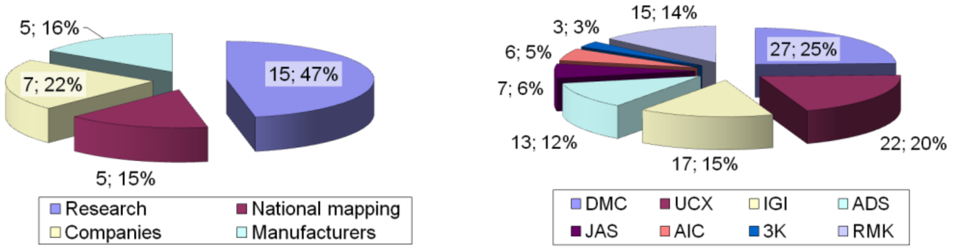
UTC 8:00h UTC 9:00h UTC 10:00h UTC 11:00h UTC 12:00h

Fig. 4: Cloud situation in western part of test site during flight day August 6, 2008 as recorded by an on-site web cam.

4 Competence teams and data evaluation

The outlines of the project were officially presented during the DGPF annual meeting in Oldenburg in spring 2008. Since then interested people mainly from the German speaking countries were invited to actively participate in this project. More than 100 different people showed interest and became part of the project mailing list. About 35 institutions signed the official project agreement fixing the common topics of analysis and a rough working schedule. An almost complete list of the test participants can be found in Cramer (2009) and on the project web site (DGPF 2009). All these participants received the requested data sets. Fig. 5 shows the structure of the project group (only active members), separated in research institutions, national mapping agencies or other organizations and companies, the later also separated into system providers / manufacturers and other commercial companies. As expected about 50% of the participants are members of the scientific sector. About one third of the participating institutions represent the commercial field. The remaining 15% are representatives from mapping organizations, representing one of the main later user groups of digital airborne sensor data and products.

The data from the different imaging sensors were altogether delivered 110 times. It is interesting to see that the major interest is on the frame based sensor systems, less than 20% of delivered data sets were from JAS-150 and ADS40. If the DMC, Ultracam-X and Quattro DigiCAM are regarded as large frame digital sensors, they together cover about 60% of all data requests. The remaining about 20% of requests was focused on the smaller format systems AIC-x1 and 3K-camera and the RMK data. The scanned analogue RMK image data mainly serve as direct comparison between analogue and digital image data quality.



Structure of expert groups

Requested and distributed data sets

Fig. 5: Participating user groups (left) and distributed data sets (right) – status as of October 1, 2009.

In order to structure the data evaluation process and to stimulate intensive discussions between different participating institutions working on the same topics, four competence teams were established, which individually focus on one of the following topics: Geometry, radiometry, digital surface models and manual stereo plotting. Each group is headed by an expert in the corresponding field: Karsten Jacobsen, Leibniz Universität Hannover (team geometry), Maria von Schönermark, former Universität Stuttgart now DLR Oberpfaffenhofen (team radiometry), Norbert Haala, Universität Stuttgart (team surface model) and Volker Spreckels RAG Deutsche Steinkohle (team stereo plotting). Many of the active participants have photogrammetric background, thus the test topics geometry and surface model generation were covered in more detail than for example the analysis of radiometric aspects of digital sensors. Therefore, the test results available so far not in all parts are as comprehensive as originally expected and consequently the publications within this PFG issue partially only reflect the current status of data evaluation.

The fact, that not all analyses could be done with such intensity as aspired is also underlined by the number of delivered results. Apparently, many of those participants, who originally requested data were finally not able to finish or even fully start the processing of the data sets. One of the main reasons was unexpected time limitations, changes in priorities and also lack of sufficient human resources. More than 80% of the participating commercial companies did not return results to any of the competence teams. From universities and national mapping agencies only 40% and 20% did not deliver any processing results.

The available results, however, already illustrate the high potential of digital imaging. The main analysis aspects and the current status of the investigations of the four competence teams are highlighted in the following papers JACOBSEN et al. (2010), HAALA et al. (2010), SPRECKELS et al. (2010). Since the radiometry team focused on the two different topics radiometric sensor calibration and land use classification two separate papers have been submitted from this group (SCHÖNERMARK (2010), WASER et al. (2010)). These papers also have to be seen in combination with previous publications, mainly in the frame of the DGPF annual meeting 2009 in Jena. These papers can also be found on the project web site (DGPF 2009). It is obvious, however, that the evaluation of this complex data needs to and will continue.

5 Summary

The DGPF project on the comprehensive empirical evaluation of digital airborne sensors and derived products is a very important milestone in the complex field of new digital sensor and product evaluation and validation. As pointed out such in-situ tests using defined processes will become one standard approach in future system certification and quality assessment of sensor products. Even though the active contributions were not as broad as hoped from the number of distributed data sets, the outcomes of this test confirm the high potential of digital sensor data recording and product processing. It is obvious that there is still a need to complete the data evaluation in the next months.

The DGPF project will officially be closed during the upcoming Dreiländertagung in Vienna in July 2010. This of course will not conclude the deeper scientific evaluations which are still pending. Topics which may be of lesser interest to participants from the operational practice, like development and testing of new image matching concepts, are seen as very valuable from a researchers' perspective. Since the high scientific value of this reference and empirical data sets is generally accepted it was already decided to make the data available for international and other research projects, too. Interested persons are cordially invited to contact the DGPF executive team members directly. We thus hope that this valuable and comprehensive data will become one of the standard empirical data sets used and cited for the next years.

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