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Article

DGPF-Project: Evaluation of Digital Photogrammetric Camera Systems – Stereoplotting

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Summary: This paper is a part of the DGPF project *"Evaluation of Digital Photogrammetric Camera Systems"* and encloses the analyses of the working group *"Stereoplotting"*. The digital imagery of the analogue camera Zeiss RMK Top 15, the digital large format frame cameras Vexcel Imaging UltraCamX and Intergraph/ZI DMC and the combination of four mid-format cameras Quattro DigiCAM from IGI have been used for stereoplotting. The individual point measurement accuracy has been determined for all cameras and ground sampling distances. The stereo-photogrammetric measurements for ground control points and for topographic point and line measurements have been compared between the cameras and to the terrestrial ground control point coordinates. The aerial flight campaigns are strongly influenced by the current weather conditions at the flying time. For this reason an – as far as possible – impartial evaluation could only be given by the comparison of the individual point measurement accuracy or identical point measurements in the mapping results of different aerial campaigns.

Zusammenfassung: ***DGPF-Projekt: Evaluierung von Digitalen Photogrammetrischen Kamerasystemen – Stereoplotting.*** Dieser Beitrag entstand im Rahmen des DGPF-Projektes „Evaluierung digitaler Luftbildkameras" und behandelt die Auswertungen der Arbeitsgruppe „Stereoplotting". Es wurden die stereophotogrammetrischen Auswertungen der Bilddaten der Reihenmesskammer Zeiss RMK Top 15 zu den großformatigen Flächensensorkameras Vexcel Imaging UltraCamX und Intergraph/ZI DMC sowie die Kombination von vier Mittelformatkameras Quattro DigiCAM der Fa. IGI untersucht. Dazu wurden die persönliche Einstellgenauigkeit in den jeweiligen Bilddatensätzen ermittelt, die stereophotogrammetrischen Messungen zu Passpunkten, topographischen Punkten und Linienmessungen in den Bilddatensätzen miteinander und zu den Soll-Koordinaten der terrestrischen Passpunktmessung verglichen. Die Bilddaten sind sehr stark durch die an den unterschiedlichen Bildflugzeitpunkten vorherrschenden Wetterbedingungen geprägt. Aus diesem Grunde kann eine möglichst objektive Beurteilung nur über die persönliche Einstellgenauigkeit und über die Ermittlung identischer Punkte in den Auswertungen der unterschiedlichen Bildflüge erfolgen.

1 Introduction

The tasks of the working group "Stereoplotting" is the analysis of the potential of digital aerial cameras for the generation of topographic maps, site plans, digital terrain models (DTM) and for 3D mapping of buildings (see Fig. 1). Up to now the results of the company RAG Deutsche Steinkohle (RAG) are available. RAG's work in this project set up by the "German Society for Photogrammetry and Remote Sensing" (DGPF) currently averages about 400 working hours. RAG has an experience in high-end photogrammetry of about 35 years (Lützenkirchen 1974, Busch 1989). Since 2004 RAG performs stereoplotting in images of digital aerial cameras and made several analyses concerning the evaluation of the geometric accuracy (Spreckels et al. 2008). Further analyses for production purposes have been performed, e. g., by Perko et al. (2004), Neumann (2004), Arias & Gomez (2007) or Talaya et al. (2008).

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Due to the expenditure of time RAG did not perform the Aerial Triangulation (AT) and used the AT results that were provided and distributed by the project management. At this it has to be taken into account that the individual point measurement accuracy of the different photogrammetric operators will have an influence on RAG's stereoplotting (see also the paper "Geometric performance", DGPF working group "Geometry"). All of RAG's stereo-photogrammetric measurements were performed by Mrs. Luzie Syrek, an operator with 23 years professional experience in stereoplotting for large area DTM and special detections for dynamic ground movements caused by underground hard coal mining. The measurements were carried out with ERDAS Imagine LPS/Pro600, NuVision stereoscopic viewing panel and polarized viewing glasses.

For the comparison of the stereoplotting results four test areas have been defined: Area 1 "Inner City", Area 2 "High Riser", Area 3 "Residential Area" and Area 4 "Quarry" (see Fig. 2).

The stereo-photogrammetric measurements for the areas 1 to 3 were performed with the aerial images in 8 cm and 20 cm ground sampling distance (GSD) of the cameras Zeiss RMK Top 15 (RMK), Intergraph/ZI DMC (DMC) and Vexcel Imaging UltraCamX (UCX). With the camera IGI Quattro DigiCAM (DigiCAM) up to now the areas 1 and 2 have been completed but the work will be continued. Area 4 "Quarry" has only been measured in the 20 cm GSD images because a comparison to the stereoplotting results from 8 cm GSD images did not show any improvement of the mapping result or considerable deviations for the DTM measurements.

For each camera RAG compared the stereoplotting results in 8 cm GSD to 20 cm GSD. Among the cameras the comparison was performed for the results from 8 cm GSD and for the results from 20 cm GSD images. As first conclusion it can be stated that the strongest influence on the photogrammetric measurements and image interpretation is due to the completely different weather conditions during the individual image flights (see Fig. 3).

For the achievements of more impartial statements of the stereoplotting results RAG decided to identify and select identical measurements for points and lines and even polygons. The individual point measurement accuracy of the operator was determined in 8 cm GSD images of the RMK, DMC, UCX and DigiCAM by the threefold measurement of all visible ground control points (GCP).

The stereoplotting results of the RMK, DMC and UCX for 8 cm GSD and 20 cm GSD that could be finished in spring 2009 have been sent to the members of the DGPF work-

Fig. 1: 3D-aspect with stereoplotting results, Area 1 "Inner City", UltraCamX, 8 cm GSD.

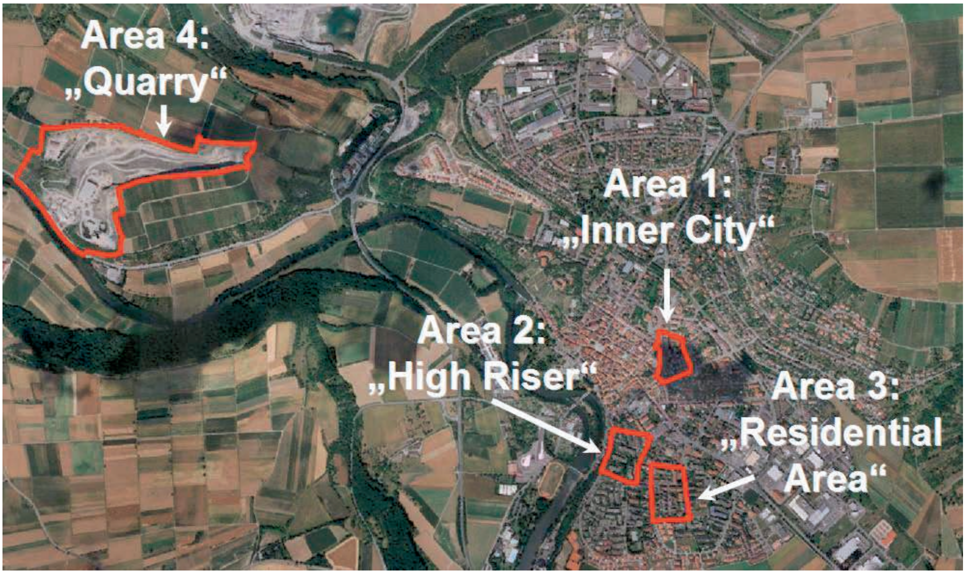

Fig. 2: Orthophoto mosaic Vaihingen-Enz, Germany, with an overview of the test areas.

Fig. 3: Aerial images of Area 1 "Inner City" at individual flying times: from left to right: '08-07-24 RMK, '08-07-24 DMC, '08-08-06 DMC, '08-08-06 DigiCAM and '08-09-11 UltraCamX.

ing group "Generation of Digital Elevation Models" as ESRI 3D-shapefiles and in MicroStation DGN format. A data set of 3D measurements of Area 1 "Inner City" with detailed building and roof structures (see Fig. 1) was sent to the project management and to the ISPRS WGIII/4, "Complex Scene Analysis and Reconstruction" in 3D-shapefile and 3DS format.

2 Stereoplotting

As far as possible it was taken into account that first of all the images of the aerial flights with 20 cm GSD were used for stereoplotting so that the measurement could not be influenced by the knowledge of the more detailed information from 8 cm GSD images. Furthermore the weather conditions to the individual flights were considered so that a flight campaign with sunny weather was followed by a flight campaign with overcast sky, what led to the following order: RMK 20 cm GSD, UCX 20 cm GSD, DMC 20 cm GSD, RMK 8 cm GSD, UCX 8 cm GSD and DMC 8 cm GSD. In autumn 2009 the stereoplotting for the two areas 1 and 2 followed for DigiCAM in 20 cm GSD and in 8 cm GSD.

The photogrammetric stereo measurements were performed using the German object-key catalogue "OSKA". All group members using

ERDAS Imagine LPS/Pro 600 got this coding from RAG for a TIPRO KeyPad for the generation of consistent and comparable data sets. The data management of all used aerial images, project data and stereoplotting results was realized on an external Buffalo Tera-Station 4 TByte raid system, connected via Ethernet to the Digital Image Station.

Work with this constellation, LPS/Pro600 and external raid system as data storage, showed a slow and tardy screen display of the digital images for all digital camera data while zooming in and out. More worse was the performance for the adjustment of contrast and brightness in dazzled areas with harsh contrasts for the aerial flight campaigns with strong insolation.

This behaviour of the screen display is most likely caused by the inherent data structure of the different images and the pre-processing and therefore not camera specific. The images were distributed in different data formats, unsigned 8 bit for UCX (670 MB/image) and RMK (1.163 MB/image), unsigned 16 bit for DMC (1.020 MB/image) and DigiCAM (402 MB/image). The tile size was 256 pixel x 256 pixel for all images.

The image pyramids were calculated anew within ERDAS Imagine LPS for DMC, UCX and DigiCAM images. In following a noticeable better performance was reached for the handling of the digital images.

Due to the dull weather with shallow contrast it was easier and more pleasant to work with the RMK 8 cm GSD and with all UCX images because nearly no adjustments for contrast and brightness had to be done implicating an efficient and uninterrupted workflow. An acceptably fast screen display resulted for RMK images with the original delivered image pyramids. The display speed was as fast as for DigiCAM with the anew calculated image pyramids and faster than for UCX images with the new LPS image pyramids – but the workstation definitely reached its limits with the display of the 16 bit DMC images even with the anew calculated image pyramids. Caused by the insolation the numerous adjustments for contrast and brightness made working with 16 bit DMC images most time-consuming (see Fig. 4).

All check measurements of GCP for the determination of the accuracy of the individual point measurement and the stereo-photogrammetric measurements were performed in Zoom Level 4 x (fourfold magnification). This ensures a consistent estimation of the digital image station's performance for stereo-photogrammetric analyses. Fig. 5 shows GCP no. 2203 in fourfold magnification for different aerial cameras.

The square GCP signals are coloured white in the size of 60 cm to 60 cm with a black coloured inner part of 30 cm to 30 cm size. In the beginning of the work RAG had reservations against this type of GCP signal but for 8 cm GSD this signalization is excellent for the measurement of GCP's when the cross-line mark reaches within the area of the white edge-strip. This allows the cross-lines to

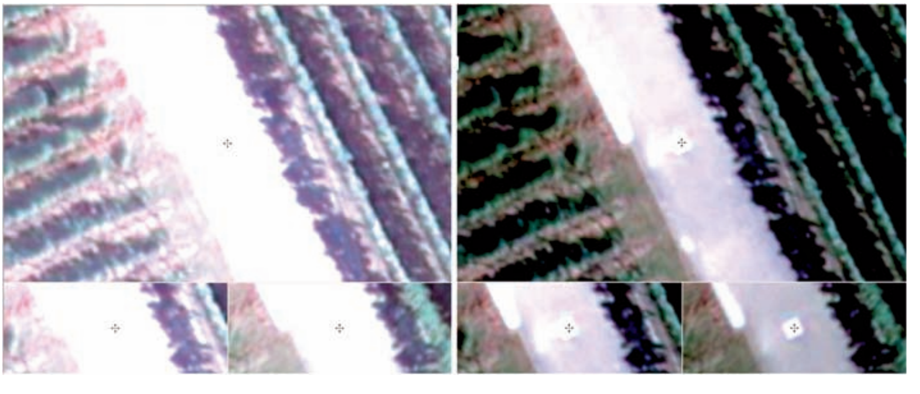

Fig. 4: GCP no.2409, Zoom Level 4 x, DMC: before (left) and after the adjustment of contrast and brightness (right). Each with the left and right image for stereo display (bottom).

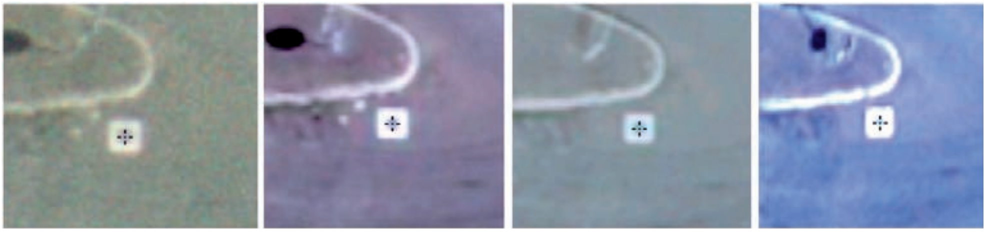

Fig. 5: GCP no. 2203, Zoom Level 4 x. From left to right: RMK, DMC, UltraCamX, DigiCAM.

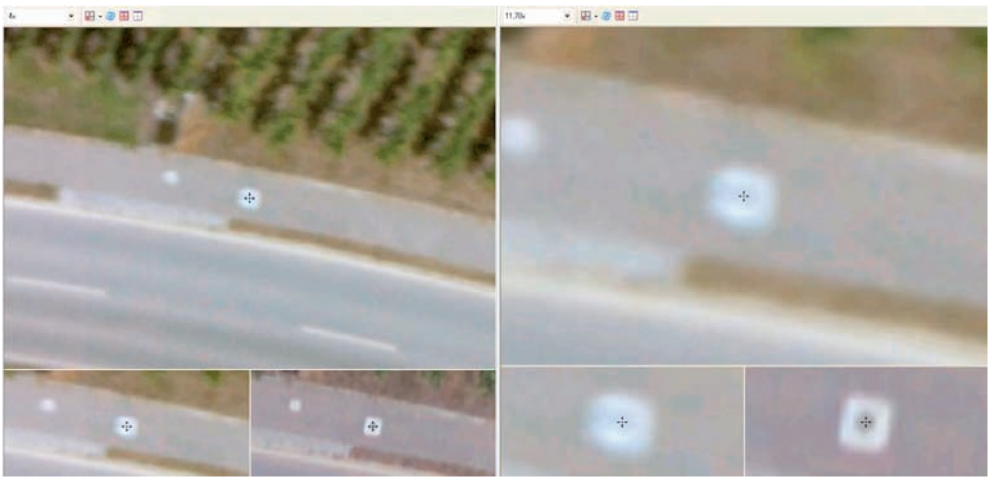

Fig. 6: Influence of the de-focused DigiCAM camera head no. 125 on GCP no. 3041029, 4 x zoom (left), 11.7 x zoom (right). Each with the left and right image for stereo display (bottom).

"lean" on the strip and prevents the mark from "sinking" into the dark area (see Fig. 5). In 20 cm GSD the inner dark part of the GCP signals is dazzled by the white strip and not visible.

Working with the four images of the DigiCAM was something getting used to. The images are taken from the same projection centers, but they are not joined together to a homogenous virtual image and for this reason they had to be handled as individual images. In LPS the four images of one flight path had to be separated into two parallel flight paths. Looking in flight direction, both right hand side images and both left hand side images were related to different flight strips. The image names were specified by the project management so that very long names evolved that often confused the assignement of the correct stereo partner. Due to the weather conditions numerous adjustments for contrast and brightness had to be done while working with DigiCAM images, but related to the smaller image size a faster screen display resulted than for DMC images. For several DigiCAM images a slight blur could be detected, as for the left stereo image that is presented in Fig. 6.

The manufacturer IGI reported that this is implicated by the focus of the camera head no. 125 to 70 m. Nevertheless it seems possible that, regarding Fig. 6, an additional influence of the forward motion of the aircraft superimposes this effect. In contrary to DMC or UCX the DigiCAM has no Forward Motion Compensation (FMC). The local areas of slight haziness do have an influence on the recognition of the objects for stereoplotting. An effort was made to automatically detect GCP in the hazy areas of the de-focused camera to be excluded from the statistical evaluation for the determination of the point measurement accuracy. The results showed an influence of about

3/8 pixel against flight direction that could be proved by re-measurements of GCP even in the left and the right stereo image.

2.1 *Comparison of Stereoplotting Results in 8 cm to 20 cm GSD*

The stereoplotting results from each camera's 8 cm GSD and 20 cm GSD images have been compared. At this point it has to be mentioned that the 20 cm GSD images of the RMK are based on a colour-infrared film (CIR) but the 8 cm GSD images are true colour (RGB) what has to be taken into account for the detection of similar features leading to diversities in image interpretation. Furthermore the CIR images of the RMK are very dazzled and for this reason not really convenient for stereo-photogrammetric measurements.

As expected, the stereoplotting results from 8cm GSD images definitely do show more details (see Fig. 7, left). They are mainly influenced by the available number of stereo models for the test area, the location of the test area within the stereo models and within one or more flight strips, as well as by the individual weather conditions. For instance kerbstones can be accentuated by the sunlight or disappear in shallow areas. Manhole cover or GCP targets can be undetectable glared. With low contrast on the other hand kerbstones cannot definitely be measured or detailed features in some areas are not clearly to be separated – but partly better in other areas. Sometimes these effects lead to misinterpretation, see Fig. 7, left hand side. Here the stereoplotting results are misinterpreted in 20 cm GSD due to the contrast and the vegetation cover. For this reason no camera specific conclusions can be made by only regarding the stereoplotting results.

2.2 *Comparison of Stereoplotting Results in 8 cm to 8 cm and 20 cm to 20 cm GSD*

For this comparison the stereoplotting results of different cameras have been combined. The substantial differences led from the influence of the weather conditions so that for instance some not hidden manhole covers could be detected in DMC images but not in UCX images – or the other way round (see Fig. 7, right hand side). Even these stereoplotting results show that no impartial validations can be made to detect camera specific characteristics. The detection and interpretation of objects depends on the already mentioned conditions like the position in a stereo model, number of stereo models and the according amount of hidden areas. At all events hard contrasts and different brightness involve additional adjustments and, for very bright areas, even the adaptation of the human eye until it was possible to continue the stereo measurements. For this reason no camera specific conclusions can be made by only looking on the stereoplotting results.

Fig. 7: Left: Area 2 "High Riser", comparison of stereoplotting results 8 cm GSD (red) to 20 cm GSD (blue), RMK. Right: Area 1 „Inner City", comparison of stereoplotting results 8 cm GSD, UCX (red) to DMC (blue).

2.3 *Comparison of Stereo-Photogrammetric Point Measurements*

Like already mentioned in sections 2.1 and 2.2, the validation of stereo-photogrammetric measurements could be successful for the detailed analysis of one specified object but not for the whole area and not for all possible combinations in 8 cm and/or 20 cm GSD. Identical points should contain the same OSKA-coding and be located within a buffer of 50 cm. Within the 3D-shapefiles of the stereo-photogrammetric measurements recognisable points with the coding 3504 (manhole cover), 3505 (gully) and 5742 (lamp pole) were selected and statistically processed, see Tab. 1. Compared to all point measurements the better recognisability of manhole covers leads to smaller deviations in position but to the same level in height (see Fig. 8).

It has to be considered that the stereoplotting in DigiCAM data is still in process and only results for Area 1 and Area 2 are present. Unfortunately the areas 1 and 2 are within the images of the de-focused DigiCAM camera head no. 125 (see Fig. 6). Re-measurements showed that this camera head has an influence on the point measurements of about 3/8 pixel against flight direction. For each flight strip this influence leads to an offset of about 2 cm to 3 cm in x for 8 cm GSD and of about 6 cm to 7 cm in x for 20 cm GSD. It has to be mentioned that for the whole block these local influences will statistically be averaged and mostly be covered. The flight direction for 8 cm GSD is from west to east, for 20 cm GSD from east to west. So the combined influences in x reach an amount of about + 7 cm to + 9 cm, what has to be taken into account regarding Tabs. 1 to 6.

Compared to RMK and UCX a smaller number of identical points could be selected for DMC. This is not camera specific but due to the more disadvantageous weather conditions that led to different point measurements within the images of the two separate image flights for 8 cm GSD and 20 cm GSD. This has to be taken into account for the comparisons presented in Tabs. 1 to 9.

The height measurements of the digital aerial cameras are around 10 cm higher compared to the scanned aerial images of RMK. A reason could be the worse point recognition in CIR images compared to RGB images. Furthermore the scanned aerial images are noisier

Tab. 1: Comparison of identical point measurements for RMK, DMC, UCX and DigiCAM, **8 cm GSD to 20 cm GSD**.

Camera	No. of points	No. of Models		mean [cm]			median [cm]			stddev [cm]		
		8 cm	20 cm	dx	dy	dz	dx	dy	dz	dx	dy	dz
RMK	125	3	4	−1,9	0,7	17,7	−0,2	0,2	18,3	10,3	9,2	14,7
DMC	92	5	4	−0,7	2,2	6,2	−0,5	2,1	4,0	12,6	9,6	18,5
UCX	129	6	2	−2,0	6,1	7,3	−1,2	6,1	5,7	9,4	8,4	18,0
DigiCAM	63	11	6	10,9	5,5	11,6	10,6	7,6	13,1	13,6	15,3	17,6

Tab. 2: Comparison of identical manhole cover measurements for RMK, DMC, UCX and DigiCAM, **8 cm GSD to 20 cm GSD**.

Camera	No. of points	No. of Models		mean [cm]			median [cm]			stddev [cm]		
		8 cm	20 cm	dx	dy	dz	dx	dy	dz	dx	dy	dz
RMK	36	3	4	−1,0	1,6	20,0	0,0	0,2	21,6	6,0	8,3	12,8
DMC	21	5	4	7,6	1,0	6,5	5,8	1,0	3,4	10,3	7,0	13,9
UCX	29	6	2	−0,6	4,8	10,1	0,3	5,4	9,7	6,4	7,1	15,1
DigiCAM	13	11	6	10,1	12,9	11,7	10,6	21,8	7,8	5,9	14,4	18,3

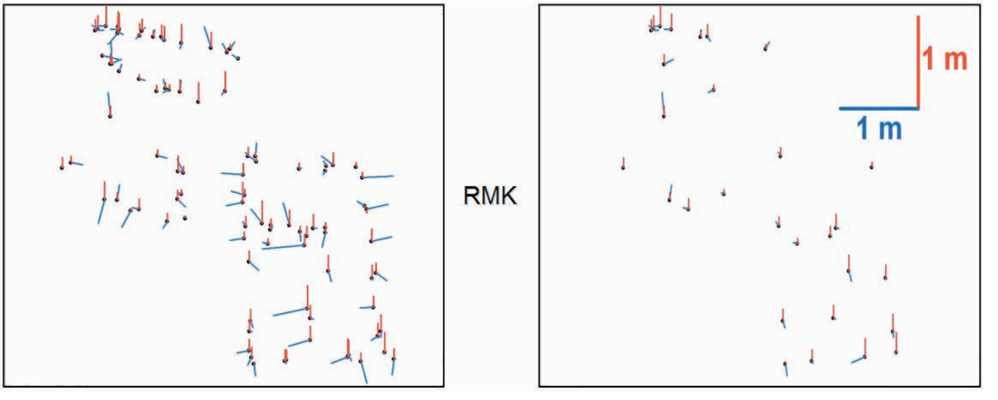

Fig. 8: Differences of all point measurements (left) and manhole cover measurements (right) for RMK, 8 cm GSD compared to 20 cm GSD for Area 2 and 3. Differences dx and dy (blue), dz (red).

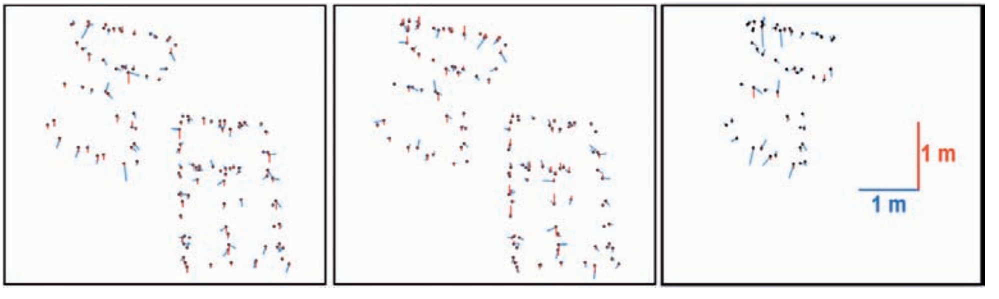

Fig. 9: Differences of all point measurements for Area 2 and 3 in 8 cm GSD. From left to right: RMK-DMC, RMK-UCX and RMK-DigiCAM (only northern Area 2). Differences dx and dy (blue), dz (red).

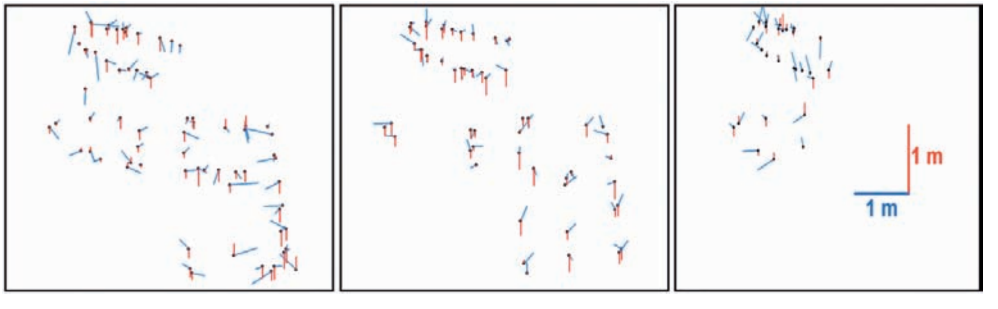

Fig. 10: Differences of all point measurements for Area 2 and 3 in 20 cm GSD. From left to right: RMK-DMC, RMK-UCX and RMK-DigiCAM (only northern Area 2). Differences dx and dy (blue), dz (red).

Tab. 3: Comparison of identical point measurements between RMK, DMC, UCX and DigiCAM, **8 cm GSD**.

Cameras	No. of points	mean [cm]			median [cm]			stddev [cm]		
		dx	dy	dz	dx	dy	dz	dx	dy	dz
RMK - DMC	182	0,6	−2,6	1,7	1,2	−2,1	2,3	5,7	5,5	10,6
RMK - UCX	183	0,9	−0,9	2,6	1,2	−0,6	2,6	6,1	5,2	11,0
RMK - DigiCAM	104	0,9	−2,5	0,8	0,7	−1,9	0,8	7,3	7,9	8,4
DMC - UCX	184	0,3	1,7	4,5	0,2	1,8	4,0	4,7	5,6	11,1
DMC - DigiCAM	108	2,5	−0,3	−2	2,2	−0,3	−2	7,1	6,6	10,3
UCX - DigiCAM	130	3,3	−1,5	4,3	3,1	−0,7	3,8	6,8	6,8	9,4

Tab. 4: Comparison of identical manhole cover measurements between RMK, DMC, UCX and DigiCAM, **8 cm GSD**.

Cameras	No. of points	mean [cm]			median [cm]			stddev [cm]		
		dx	dy	dz	dx	dy	dz	dx	dy	dz
RMK - DMC	53	−1,1	−1,9	−3,1	−1,3	−1,8	−3,4	2,9	5,2	7,7
RMK - UCX	54	−1,0	−0,5	2,9	−0,9	−0,6	2,6	3,6	4,9	8,3
RMK - DigiCAM	36	−0,1	0,2	1,2	−0,4	−0,8	−1,3	4,2	5,5	6,2
DMC - UCX	54	0,0	1,2	5,5	0,1	1,6	5,3	3,0	3,9	8,1
DMC - DigiCAM	35	0,9	0,3	−1,0	1,1	−0,1	−1,5	4,9	5,0	8,3
UCX - DigiCAM	45	1,7	−0,3	−6,3	2,5	−0,4	−5,0	4,8	4,8	7,2

Tab. 5: Comparison of identical point measurements between RMK, DMC, UCX and DigiCAM, **20 cm GSD**.

Cameras	No. of points	mean [cm]			median [cm]			stddev [cm]		
		dx	dy	dz	dx	dy	dz	dx	dy	dz
RMK - DMC	97	−0,6	−2,1	− 9,7	− 0,6	−1,2	− 7,8	14,5	11,6	21,5
RMK - UCX	88	−0,9	2,3	−11,6	0,3	1,9	−18,5	9,4	10,6	23,3
RMK - DigiCAM	51	−6,6	2,3	0,9	− 6,9	1,5	− 1,5	14,3	17,0	18,3
DMC - UCX	72	−1,5	3,5	0,3	− 1,7	2,6	− 0,6	15,2	11,9	20,3
DMC - DigiCAM	37	−7,5	3,1	5,3	−11,6	3,6	2,7	18,0	14,3	23,4
UCX - DigiCAM	50	−7,1	1,1	2,1	− 9,0	2,1	5,3	14,1	13,3	25,4

Tab. 6: Comparison of identical manhole cover measurements between RMK, DMC, UCX and DigiCAM, **20 cm GSD**.

Cameras	No. of points	mean [cm]			median [cm]			stddev [cm]		
		dx	dy	dz	dx	dy	dz	dx	dy	dz
RMK - DMC	20	7,5	−2,8	−14,1	6,8	−2,2	−17,0	11,7	8,8	20,7
RMK - UCX	22	−0,7	0,2	− 4,2	0,1	0,4	− 9,5	8,9	9,7	22,6
RMK - DigiCAM	11	−8,4	1,9	− 6,4	− 8,1	1,1	− 6,2	7,3	16,1	12,7
DMC - UCX	13	−6,7	3,6	1,7	− 6,5	0,9	5,0	10,5	11,3	14,0
DMC - DigiCAM	5	−19,3	8,9	− 4,1	−20,2	12,1	1,2	5,2	12,4	24,1
UCX - DigiCAM	11	−9,3	1,8	− 8,9	− 9,0	1,4	−26,5	7,8	14,3	29,1

than the digital aerial images leading to less precise height measurements. These height differences between scanned aerial images and digital aerial images correspond to RAG's experience on current projects for site plans and time series for earthworks on mine waste heaps, as up to 2008 only analogue cameras were used and from 2009 on selected digital aerial cameras. In the following a summary of these comparisons presented in Tabs. 3 to 6 will be given:

8 cm to 20 cm GSD, for each camera:

- For the RMK the stereo-photogrammetric height measurements in 8 cm GSD images are about 18 cm to 20 cm above the height measurements in 20 cm GSD.
- For the digital aerial cameras the stereo-photogrammetric height measurements in 8 cm GSD images are about 6 cm to 9 cm above the height measurements in 20 cm GSD.
- In 8 cm GSD images the dark inner part of the GCP is visible but not in 20 cm GSD. This leads to better point measurement conditions in height for 8 cm GSD images.

8 cm to 8 cm GSD, between different cameras:

- The accuracy for position measurements regarded between all cameras is 0.9 pixel and better.
- The accuracy for height measurements regarded between all cameras is 1.4 pixel and better.

20 cm to 20 cm, between different cameras:

- The accuracy for position measurements regarded between all cameras is 0.9 pixel and better.
- The accuracy for height measurements regarded between all cameras is 1.4 pixel and better.
- The RMK and DigiCAM height measurements are nearly on the same level. The height measurements of the RMK are about 10 cm below the height level of DMC and UCX, DMC and UCX are nearly on the same height level.

2.4 *Comparison of Stereo-photogrammetric Line Measurements*

An attempt to analyse stereo-photogrammetric line measurements from different stereo-plotting results was made. Fig. 11 presents a comparison of stereo-photogrammetric line measurements in 8 cm GSD for RMK and DMC.

For this purpose identical points on lines within a buffer of 1 m for the OSKA-coding 5101 (road) and 5201 (path) have been selected. For these selected lines the attributes "no. of lines", "no. of line points", "difference in

Fig. 11: Line measurements in 8 cm GSD images for RMK (red) and DMC (blue). Background image: UCX orthophoto, 8 cm GSD.

Tab. 7: Comparison of identical line length measurements for RMK, DMC and UCX, **8 cm GSD to 20 cm GSD**.

Camera	No. of lines	mean dl [cm]	median dl [cm]	stddev dl [cm]
RMK	83	5,3	2,1	7,4
DMC	57	8,7	3,7	10,1
UCX	87	5,7	2,1	7,6

Tab. 8: Comparison of identical line length measurements for RMK, DMC and UCX, **8 cm GSD**.

Cameras	No. of lines	mean dl [cm]	median dl [cm]	stddev dl [cm]
RMK - DMC	85	2,9	1,4	4,8
RMK - UCX	102	4,2	2,3	5,3
DMC - UCX	111	3,2	1,2	5,0

Tab. 9: Comparison of identical line length measurements for RMK, DMC and UCX, **20 cm GSD**.

Cameras	No. of lines	mean dl [cm]	median dl [cm]	stddev dl [cm]
RMK - DMC	65	7,4	3,0	10,6
RMK - UCX	83	4,7	2,0	7,7
DMC - UCX	57	7,3	2,8	9,0

length (dl)", "difference in position" and "shortest distance between lines" have been determined.

The comparisons in Tabs. 7 to 9 show that the identity of lines depends on the detectability of features due to weather conditions, the GSD and the better image quality of digital images. As it could be expected more identical lines were found for 8 cm GSD than for 20 cm GSD. The weather conditions for the DMC flight campaign seem to be worse for stereoplotting purposes compared to RMK or UCX. Due to the contrast the visual perception of edges, like for kerbstones, is different between RMK and UCX or RMK and DMC in 8 cm GSD and in 20 cm GSD. But in 8 cm GSD UCX to RMK and UCX to DMC show a similar amount of identical lines. The influence of shadows leads to differences in position involving a smaller number of identical lines between RMK and UCX to DMC line measurements. But more interesting is the largest number of identical lines that was found for UCX and DMC in 8 cm GSD what leads to the assumption that in this case the possibility to detect more detailed features in 8 cm GSD outmatches the influence of the insolation.

Even this comparison affirms the influence of the weather conditions in the way that no camera specific conclusions can be made by only regarding the stereoplotting results.

2.5 *Determination of the Individual Point Measurement Accuracy and Differences to GPS Coordinates*

Within the up to now presented comparisons and analyses the measurements of topographic points and lines were considered. For a more impartial analysis of the stereo-photogrammetric measurement accuracy, all GCP were triply re-measured in the 8 cm GSD images of RMK, DMC, UCX and DigiCAM. So the operator's individual point measurement accuracy could be determined (see Tab. 10).

Differing to the practical experience also the GCP outside the 60 % end lap stereo model

Tab. 10: Individual point measurement accuracy, **8 cm GSD**.

Camera	Points in area	No. of GCP	No. of measure-ments	Individual point measurement accuracy [cm]								
				|x|			|y|			|z|		
				max	mean	std	max	mean	std	max	mean	Std
RMK	model	60	645	0,9	0,4	0,2	1,2	0,4	0,2	1,1	0,4	0,2
	border	45		0,9	0,3	0,2	1,3	0,4	0,2	1,0	0,4	0,3
DMC	model	58	735	1,2	0,4	0,2	1,6	0,4	0,2	1,6	0,6	0,3
	border	55		1,0	0,4	0,2	1,6	0,5	0,2	1,8	0,6	0,3
UCX	model	58	741	1,0	0,4	0,2	1,5	0,4	0,2	1,9	0,6	0,4
	border	50		1,2	0,4	0,2	1,1	0,5	0,2	1,7	0,6	0,3
DigiCAM	model	56	591	1,4	0,4	0,3	1,8	0,5	0,3	1,8	0,4	0,3

Fig. 12: Triply GCP re-measurements: Border lines of model area (yellow) and border area (red) for RMK, 8 cm GSD images.

area were measured to gain additional information about the measurement accuracy in the border areas (see Fig. 12). Depending on the four camera head technology it was not possible to allocate point measurements to the border areas for the DigiCAM. By this means the operator's individual point measurement accuracy could be determined to 0.5 cm in position and 0.6cm in height for all cameras in 8 cm GSD.

As already noted the stereo-photogrammetric point measurements still contain the influences of the AT. To describe and illustrate these deviations the manifold GCP measurements were compared to the coordinates of the terrestrial GPS measurements (see Tab. 11).

It can be noticed that the height measurements in the border areas of the RMK are noticeable worse than in the 60 % end lap stereo model area. Over all the differences of the photogrammetric point measurements within the stereo model area compared to the GPS coordinates reaches an amount of better than 0.25 pixel in position and about 0.6 pixel in height.

Tab. 11: Differences of the threefold GCP re-measurements to the GPS coordinate.

Camera	Points in area	No. of GCP	No. of measure-ments	Difference to the GPS coordinate [cm]					
				x		y		z	
				mean	stdev	mean	stdev	mean	stdev
RMK	model	60	125	−1,0	2,4	1,1	3,5	1,1	7,5
	border	45	90	−0,9	2,4	0,5	3,8	4,4	7,5
DMC	model	58	122	−1,2	1,8	1,8	2,8	−1,3	3,4
	border	55	123	−1,3	1,9	2,3	2,6	−1,9	3,8
UCX	model	58	134	−2,2	1,2	1,6	2,1	0,2	4,8
	border	50	113	−2,4	1,4	1,8	2,2	−2,1	5,4
DigiCAM	model	56	197	−1,0	1,9	0,8	2,6	−2,9	3,4

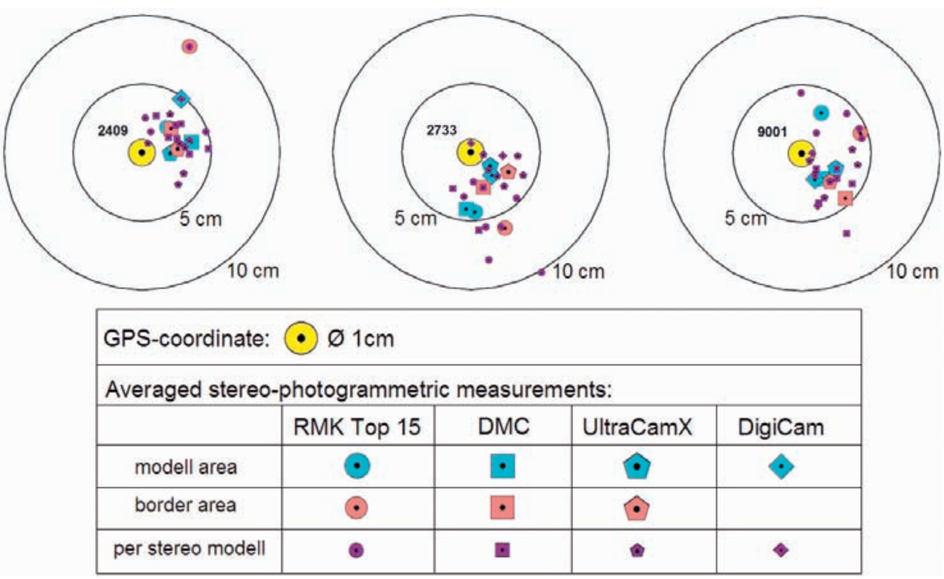

Fig. 13: Overview of the stereo-photogrammetric point measurements in 8 cm GSD for selected GCP related to the GPS coordinate. From left to right: GCP no. 2409, 2733 and 9001.

Fig. 13 shows the spreading of the point measurements related to the GPS coordinate for the three exemplarily chosen GCP 2409, 2733 and 9001. The circles show the 5 cm and 10 cm distance around the GPS coordinate. The blue symbols present all averaged GCP measurements in 8 cm GSD within the model area and the light red symbols the averaged GCP measurements for the border areas. Violet coloured symbols show the averaged location of each triply stereo-photogrammetric measurement. It can be seen that the measurements in the images of all different cameras build clusters that lie relatively close to each other. The different location related to the GPS coordinate may give hints about the effects of the AT and bundle block adjustment.

3 Summary and Outlook

The comparison and analysis of the stereoplotting results for the RMK Top 15, DMC, UltraCamX and Quattro DigiCAM revealed the strong influence of the weather conditions, mostly the insolation. The different conditions for the flight campaigns in July, August, and September 2008 superimposed possible camera specific characteristics.

A non-camera specific point but important for the stereoplotting is the slow screen display by zooming in and out and, what is more, for the adjustment of brightness and contrast. This behaviour is caused by the inherent data structure (8 bit or 16 bit) of the digital aerial cameras images. Only with anew processed image pyramids for DMC, UltraCamX and DigiCAM the workings were feasible.

A difference in height with the amount of about 1 pixel could be depicted between scanned aerial images and digital images. The knowledge of this height difference is necessary if height measurements or DTM from diverse camera systems have to be compared. The analysis of the individual point measurement accuracy for RAG's operator was about 0.5 cm in position and 0.6 cm in height in all cameras' 8 cm GSD images. The difference of manifold re-measured GCP in 8 cm GSD images to the GPS-coordinate was in the amount of about 0.25 pixel in position and about 0.6 pixel height.

The accuracy between all cameras in 8 cm GSD and in 20 cm GSD was better than 0.9 pixel in position and 1.4 pixel in height. For the Quattro DigiCAM it has to be taken into account that one of the four camera heads was de-focused. It took getting used to work with the particular four image technique of the Quattro DigiCAM.

No recommendation for the one or the other camera can be given because this project showed that in daily practice the changing conditions like weather or insolation provide more uncertainties than the camera specific characteristics. The decision about which camera to use should thoroughly be considered by the application, the needed technical possibilities and the economic conditions.

In 2010 RAG will continue the working on Quattro DigiCAM and begin with Leica Geosystems ADS40 (2nd generation). Upon completion the stereoplotting results will be compared to the results of other group members that have to be expected in 2010.

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