PHOTOGRAMMETRIC STEREOPLOTTING CAPABILITIES OF VEXCEL ULTRACAM$_D$ DIGITAL AERIAL IMAGERY

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KEY WORDS: Vexcel UltraCam$_D$, Digital Aerial Imagery, Stereoplotting, Colour Calibration, Radiometry, Geometric Resolution.

ABSTRACT:

Deutsche Steinkohle AG is the German hard coal mining company and owns the one and last coking plant in Germany. As a result of the global shortage and selling conditions of coke coal -a need for steel production- planning activities for an extension of the coking plant began in autumn 2004. The existing site plans are out-of-date and imprecise. Due to costs and the time schedule a complete terrestrial survey was impossible. Only photogrammetric stereoplotting had the capability for an accurate in-time survey. This decision was made in October 2004 so that according the low sun position and resultant shading only digital aerial camera systems could be able to deliver analysable images for this industrial site with building heights of up to 100 meter above ground level (a.g.l.). Unfortunately the flight campaign was protracted due to adverse weather until December 2004. The images were taken using the digital aerial camera Vexcel UltraCam$_D$. The main focus was set on most accurate ground truth. For an analysis of the real ground sampling distance (GSD) in mono- and stereo-view several plates with geometric patterns were prepared. To get full information all spectral channels were registered. For the colour calibration and radiometric analysis colour plates were painted with “RAL colours” that follow DIN regulations, contain colour samples and even the colour distances measured by spectrophotometers. Additionally the reflectance of the RAL cards and of the colour-plates were measured with a spectroradiometer under laboratory conditions. The aerotriangulation, bundleblock adjustment, the generation of digital elevation models (DEM) and orthophoto-mosaics as well as the stereoplotting for the site plans were performed on digital photogrammetric workstations. The whole workflow shows a high accuracy and stability. Above all the high information content of the digital images made it possible to measure nearly all objects for the whole area of an industrial site, in images that were taken under most unfavourable conditions.

1. INTRODUCTION

Deutsche Steinkohle AG owns the one and last coking plant “Prosper” near the city of Bottrop, Germany. As a result of the global shortage of coke coal that is needed for steel production, planning activities for an extension of the coking plant began in autumn 2004. The existing site plans were out-of-date and imprecise. Due to costs and the time schedule a complete terrestrial survey was impossible. Only photogrammetric stereoplotting had the capability for an accurate in-time survey and in October 2004 the decision for a photogrammetric survey was made. According to the low sun position and resultant very long shading only digital aerial camera systems could be able to deliver analysable images for this industrial site with building heights of up to 100 meter (see Figure 1).
It could be foreseen that the aerial images would be taken under unfavourable conditions. For this reason the main focus was set on most accurate ground truth. 46 ground control points (GCP) were signalised on an area of about 24 km². These points and the projection centres of the images were registered with an accuracy of less than 3 cm in position and height by differential GPS in the ETRS89 coordinate system, stuck to the German SAPOS-Stations. The transformation from the ETRS89 to the Gauß-Krüger coordinate system is realised by fixed official transformation parameters for the area of the DSK [Spreckels 2003]. The projection centres of the aerial images were registered with highest accuracy by using calibrated GPS and INS/IMU data.

Figure 1. Coking Plant “Prosper”, Bottrop, Germany.

Five east-west flight strips were planned with a ground sampling distance (GSD) of 10 cm (about 1.200 m flying height a.g.l., image scale 1:5.000) and four object flight strips with 8 cm GSD (about 980 m flying height a.g.l., image scale 1:4.000) with 80% end lap and 30% side lap. This configuration with one cross flight strip should avoid blind areas (see Figure 2).

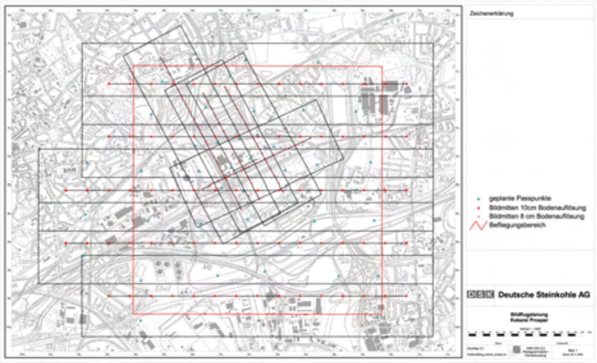

Figure 2. Flight Mission and GCP Planning.

2. FLIGHT CAMPAIGN

The weather conditions prevented a flight campaign until December 10th, 2004. Despite the estimation of poor image quality the flight got allwance. The images were taken with the digital camera Vexcel UltraCam$_D$ [LEBERL 2003, GRUBER 2004, KRÖPFL 2004]. This camera is able to record multispectral images in 4 spectral channels red, green, blue and near infrared. For technical data see Table 1.

Sensor Type	Area CCD
Number of CCD Cameras	9
Focal length (pan)	101,4 mm
Focal length (ms)	28 mm
Field of View	55° x 37°
Pixel size	9 µm
Radiometric Resolution	> 12 bit
CCD Format along flight (pan)	11.500
CCD Format across flight (pan)	7.500
CCD Format along flight (ms)	4.008
CCD Format across flight (ms)	2.672
Read-Out Frequency	0,75 images/second
Stabilisation Platform	Zeiss T-AS, FMC
Spectral Channels	Spectral Resolution, Wavelength in nm
panchromatic	390 - 690
blue	390 - 470
green	420 - 580
red	620 - 690
near infrared	690 - 900

Table 1. Vexcel UltraCam$_D$: technical data.

Owner of this camera is the company *GeoTec GmbH*, Prenzlau/Germany [GEOTEC], the flight was performed by *Weser Bildmessflug*, Bremervörde/Germany [WBF]. The flight campaign took place between 1 and 2 o'clock p.m. at a sun position of 16° to 14° above the horizon (see Figure 3) what lead to long shading (see Table 2).

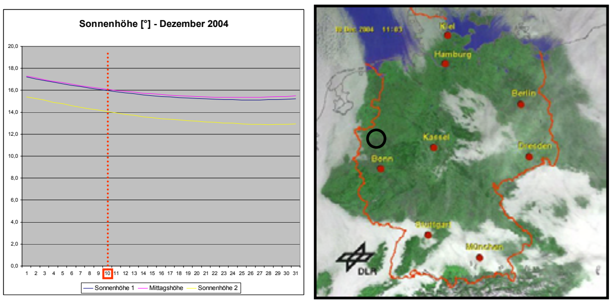

Figure 3. Sun elevation during flight campaign and weather conditions on December 10th, 2004, 1 to 2 o'clock p.m. (image courtesy DLR). Black circle: location of the flight area.

Sun elevation	Shadow length for an object-height = 100 meter
14°	400 m
15°	375 m
16°	350 m

Table 2. Sun elevation and shadow length.

Because of the unusal flight period the image processing was done at DSK with the aid of *GeoTec*. The colour plates (see Figure 8) were very useful for the processing of "level3" images that are used for stereo measurements and orthophoto generation. For working in LPS/PRO600 three-band data is needed and so the images were processed twice using the three spectral channels RGB and CIR. The file size slightly differs for Erdas Imagine IMG- and TIFF-format:

Format	Image	Image pyramids
Erdas Imagine IMG	256 MB	86 MB
TIFF	260 MB	89 MB

Table 3. File format and image size.

One process in coke coal production is the extinguishing of the coal in sporadic intervals. Hereby big steam clouds suddenly emerge - so some flight strips had to be flown for several times. One east-west flight at 10 cm GSD strip had to be flown twice, one object strip at 8 cm GSD triply. In total 283 images were taken and used for the aerotriangulation. According to table 3 all these 283 images require 99 GB disk space.
For the stereoplotting 130 images at 10 cm GSD and 77 images at 8 cm GSD could be used.

3. DATA PREPARATION

3.1 GPS Measurements for Ground Control Points

For the flight campaign 45 GCP had been signalised. These consist of a central white square of 30 cm x 30 cm and white coloured wings at the size of 30 cm x 120 cm. The coordinates of the signal centres were measured twice by differential GPS stuck to the SAPOS station no. 582 Essen [SAPOS] at a distance of about 10 km.

DSK demands an accuracy < ± 3 cm for these GCP measurements. The deviation to the mean value was lower than 1,5 cm for all GCP:

BLAN-Analysis for dual GCP Measurements [BLUH]:

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SQUARE MEAN OF DIFFERENCES
 SX = +/-   .007   SY = +/-   .013   SZ = +/-   .014
 NX =        45   NY =        45   NZ =        45

 MAXIMAL DIFFERENCES
 MAX DX =   .015   MAX DY =   .036   MAX DZ =   .034

 SYSTEMATIC DIFFERENCES
 SYSTX =    .001   SYSTY =    .000   SYSTZ =   -.002
 SQUARE MEAN OF DIFFERENCES WITHOUT SYSTEMATIC
DIFFERENCES
 SX = +/-   .007   SY = +/-   .013   SZ = +/-   .014
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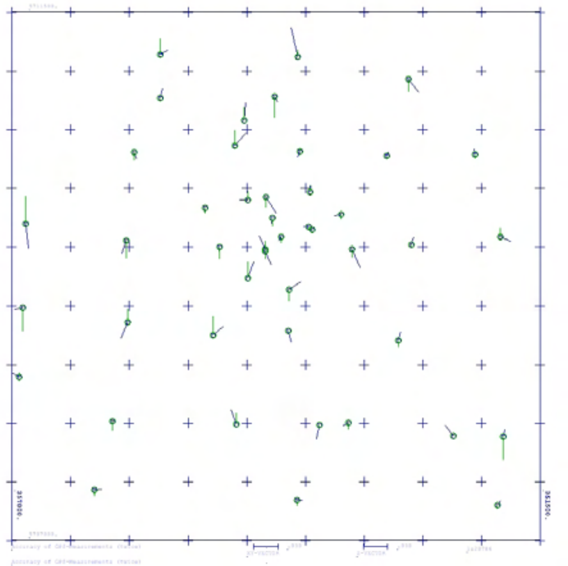

Figure 4. BLAN Analysis of dual dGPS GCP-measurements (x,y,z-scale: 3 cm).

3.2 Aerotriangulaton and Bundleblock Adjustment

Aerotriangulation and Bundleblock Adjustment were performed with *Leica Photogrammetry Suite (LPS)* and *ORIMA*. Results see Figure 5 and Table 4.

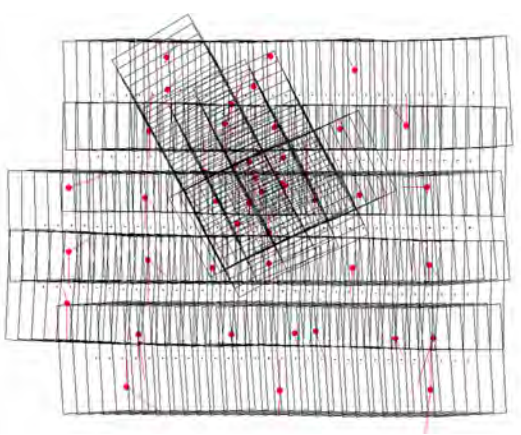

Figure 5. Aerotriangulation results using ORIMA.

Aerotriangulation with ORIMA			
	RMS	Max. Deviation	In Point
X	0,0215 m	0,0603 m	36
Y	0,0331 m	-0,0689 m	35
Z	0,0355 m	0,0789 m	38
σ_0	2,9µm		

Table 4. Results of ORIMA - Aerotriangulation.

The generation of digital elevation models and orthophoto-mosaics (see Figure 6) as well as the stereoplotting for the site plans is performed with *LPS / PRO600*.

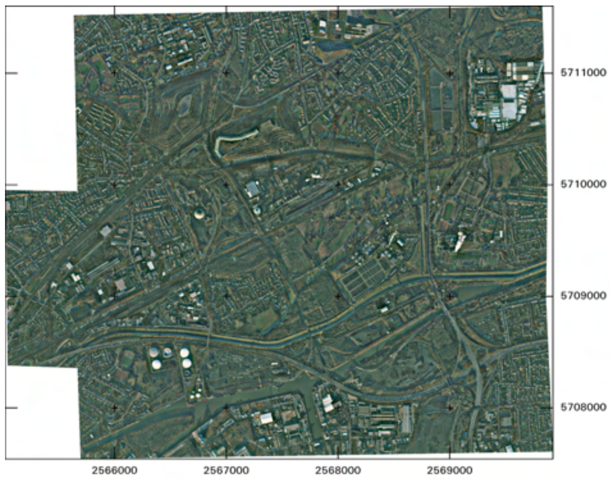

Figure 6. Orthophoto Mosaic. Grid distance: 1 km.

The work done so far shows a high accuracy and stability within the whole workflow. One negative notation for the used camera was the lightening of gray values from the image centre to the edges, especially in the green spectral channel. For this reason the generation of the orthophoto mosaic had to be performed only by using the central image parts. Above all the high information content of the digital images made it possible to measure nearly all objects for the whole area of an industrial site

4. GROUND SAMPLING DISTANCE, RADIOMETRY AND COLOUR CALIBRATION

4.1 Ground Sampling Distance

For an analysis of the real ground resolution in mono- and stereo-view test plates with different geometric patterns and several "Siemens-Stars" were prepared with diameters up to 1,8 meter (see Figure 7). By measuring the diameter of the blurred gray-area compared to the diameter of the "Siemens-Star" and the number of black/white segments the actual ground resolution can be calculated.
These measurements were performed under PRO600 in mono- and stereoscopic view at the stereo workstation. The images / stereomodels 210-211 were used for the 8 cm GSD and 269-270 to evaluate 10 cm GSD. Table 5 shows the results of monscopic and stereoscopic measurements (PRO600).

	Siemens-Star", Ø 1,80 meter			
	Monoscopic-View		Stereoscopic-View	
Siemens Segments	48	24	48	24
Resolving Power:	[cm]	[cm]	[cm]	[cm]
GSD: 8 cm	7,8 – 8,0	8,9 – 9,4	7,5 – 8,0	8,0 – 10,0
GSD: 10 cm	%	13,0 – 14,5	%	10,0 – 12,0

Table 5. Measurements for effective Ground Sampling Distance (GSD) using "Siemens-Stars" with 24 and 48 black/white segments. Measurements performed with PRO600.

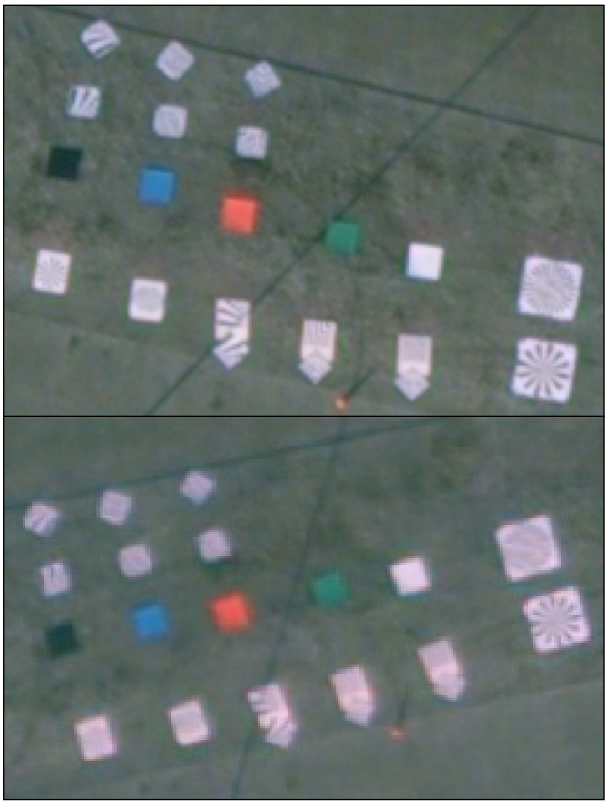

Figure 7. Plates for geometric and radiometric evaluation. Upper image 8 cm GSD, lower image 10 cm GSD.

4.2 Radiometry and Colour Calibration

The ground sampling distance (GSD) is of key importance for stereoscopic analyses. Besides information about geometric tasks also knowledge about the radiometric resolution is clearly of interest. Therefore two different aspects have to be considered:

- control and evaluation of the radiometric quality over the entire area of the individual image,
- image calibration with respect to further analysis, especially related to image interpretation tasks.

The second point will become more important within the near future, because DSK is obliged to conduct large scale aerial surveys to provide CIR data sets to monitor especially forests stands. Manual interpretation and development of interpretation keys have been done so far using conventional CIR-photos. Due to the new sensor developments those works have to be done on the basis of digital imagery in the near future. Therefore aspects related to image calibration will become more important.
To get full information all spectral channels, red, green, blue and near infrared were registered. For the colour calibration and radiometric analysis five 1m x 1m colour plates were prepared with so called "RAL colours" [RAL] in black, white, red, green and blue (see Figure 7). These "RAL colours" follow DIN regulations, contain colour samples and even the colour distances measured by spectroradiometers (see Figure 8).

Additionally the reflectance of the five colour-plates and the RAL cards was measured with a spectrometer under laboratory conditions at the *Institute for Geotechnical Engineering and Mine Surveying, Technical University of Clausthal (IGMC)* (see Figure 8).

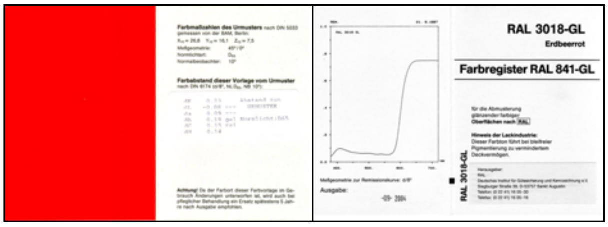

Figure 8. Example for RAL colour and colour sample

The measurements were made with a spectroradiometer FieldSpec Pro FR by ASD [ASD]. This device has a spectral range from 350 – 2500 nm with a spectral resolution of 1.4 nm in the range from 350 nm to 1050 nm. The measurements of the RAL cards as well as from the plates serve as basis. First the measurements made from the RAL cards were controlled under use of the printed information of each card (see Figure. 9). Due to different measurement devices minor differences of the reflectance curves occur. Together with the measurements of the plates different reflectance curves were select.

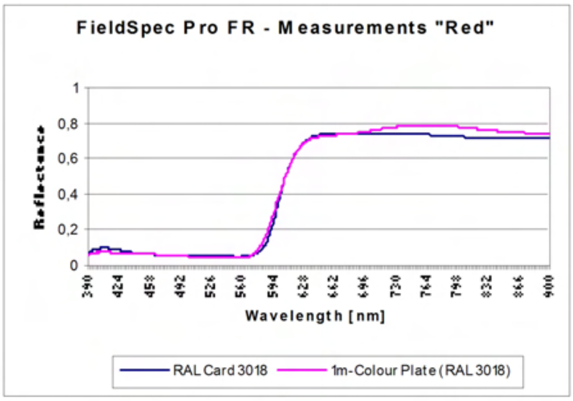

Figure 9. FieldSpec reflectance measurements, color red (RAL 3018): Mean of 10 spectral profiles for the RAL Card (blue line) and the mean spectral profile of 25 measurements (five measurements in each corner and the plate center) for the colour plate (magenta line).

The reflectance curves were used to perform initial investigations to convert the radiances of the images into reflectance values. Therefore the empirical line calibration approach was used [SMITH, MILTON 1999]. Due to the time and weather related conditions of the flight campaign, only first investigations were possible.
Based on the initial work it seems to be necessary to put coloured plates at different location within the next flight campaign. This is the prerequisite to process the image completely. For spectral measurements within the digital multispectral imagery the size of the used plates should be extended to 1,6m x 1,6m at 8 cm GSD or 2,0m x 2,0m at 10 cm GSD, the fivefold multiple of the multispectral pixel size
At this time it was not possible to perform a proper correction of the whole imagery to remove influences caused by the solar irradiance and the atmospheric path radiance. Further investigations have to be done. But it can clearly be stated that the concept described can be used to provide the reference data needed and that the method could serve as important constituent for further works to establish a quality assessment. So it should be possible to derive the offsets in colour for the used plates and the atmospheric conditions during the flight campaign to the image data.

5. STEREOPLOTTING (3D MEASUREMENTS)

5.1 Potential of 12bit imagery, RGB and CIR

The aim of this late flight campaign was to derive high accurate 2D- and 3D-site plans for the area of the coking plant and the neighboured coal deposit areas.

Figure 10. Detail of image no. 210, 8 cm GSD, true colour RGB. Upper image: non-stretched histogram, lower image: histogram stretched.

For the stereo measurements even the CIR images were processed because their potential for the detection of more details than in RGB imagery should be checked.
The radiometric resolution of more than 12 bit made it possible to reduce the influence of the shadows and to do 3D-measurements for nearly all areas. Figure 10 shows a detail of picture no. 210 where a lot of more details are visible only through a simple histogram stretch – this comparison gives an impression of the radiometric potential of digital aerial cameras. Figure 11 shows the same area for the CIR imagery.

Figure 11. Detail of image no. 210, 8 cm GSD, false colour CIR. Upper image: non-stretched histogram, lower image: histogram stretched.

Figure 12 (next page) gives an impression of the potential of 12 bit imagery by 3D-anaglyph images that show non-stretched and histogram stretched stereo images, overlaid with photogrammetric measurements.

5.2 Photogrammetric Measurements

The aerial images covered an area of about 18 km² (see Figure 6). All photogrammetric measurements cover an area of 232 hectares (ha), the industrial site of the coking plant "Prosper" has an area of approximately 61 ha.
Due to the high and densely constructed buildings long shading had an influence to the object detection. For this reason the flight was planned with 80% end lap and an additional cross strip along the alignement of the coke coal production line. This configuration could avoid most blind areas. If a direct 3D measurement seemed impossible at

60% overlap the point location was solved in 80% overlap and the height was measured in another model of another strip at 40% or 60% overlap.

Not only fume and steam had an influence to the images, what is more is the dirt of coal dust lubrication on the ground. Thus the ground control points had to be cleaned every two weeks.

The shadowing plus lubrication dirt at some places seemed to lead to very low contrast even in 12 bit imagery and to imprecise measurements with lower accuracy in height (see Figure 14). Nevertheless terrestrial measurements had to be made e.g. for the detection of quoins that are covered by roof extensions or details that were hidden or could not clearly be resolved due to the image resolution.

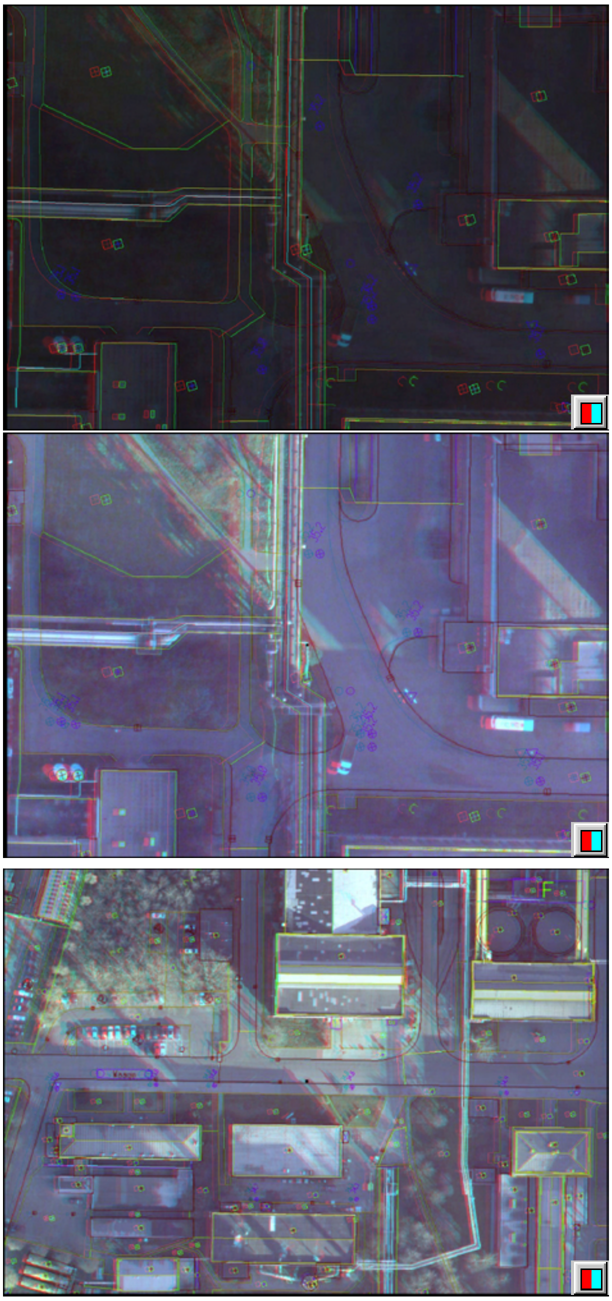

Figure 12. Anaglyph stereo-images and stereoplotting for shadow-areas: non-stretched histogram (upper image), stretched histogram (mid image) and overview (lower image).

To cover the 61 ha area of the coking plant 17.974 photogrammetric point measurements of the new site plan are present. Only additional terrestrial measurements of 160 points were necessary; a relation of ~ 0,9% (see Figure 13).

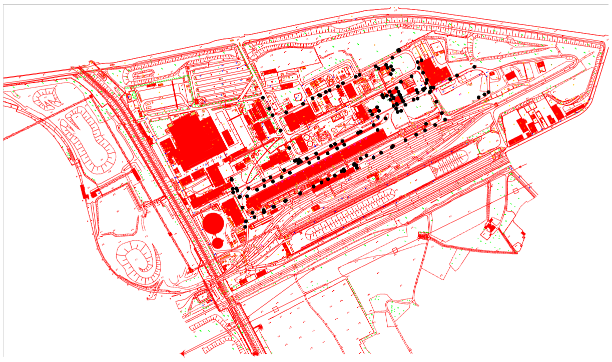

Figure 13. Comparison of photogrammetric measurements (coloured) and terrestrial measurements, mainly manhole covers and quoins (black dots).

A lot of these points were manhole covers and some of these have been measured for a comparison of photogrammetric and terrestric points by BLAN analysis:

Manhole Covers:	Photogrammetric:	159,
	Terrestrial:	119,
	Identical points:	75,

Additional terrestrial measured manhole covers: 44,
Quoins, Pillars of Pipe Bridges etc.: 41.

BLAN Analysis:

SQUARE MEAN OF DIFFERENCES
SX = +/- .043 SY = +/- .041 SZ = +/- .119
NX = 75 NY = 75 NZ = 75

MAXIMAL DIFFERENCES
MAX DX = -.119 MAX DY = -.134 MAX DZ = .244

SYSTEMATIC DIFFERENCES
SYSTX = .016 SYSTY = -.008 SYSTZ = .079
SQUARE MEAN OF DIFFERENCES WITHOUT SYSTEMATIC DIFFERENCES
SX = +/- .040 SY = +/- .040 SZ = +/- .090

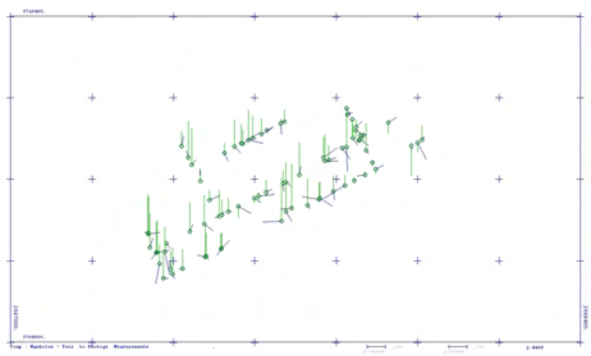

Figure 14. BLAN Analysis of differences between terrestrial and photogrammetric measurements of manhole covers in shadowing areas with coal dust lubrication (x,y,z-scale: 10 cm).

6. CONCLUSION AND OUTLOOK

The successful photogrammetric stereoplotting for site plans by the use of digital 12 bit aerial images of the UltraCam$_D$ taken in December shows the high geometric and radiometric potential of digital aerial cameras. It can be stated that the high resolution camera system have enormous advantages in comparison to conventional camera systems. This is not only related to the GSD flown it is also related to the radiometric resolution which allow stereoscopic measurements even under not favourable conditions.

For the generation of industrial site plans the near infrared spectral channel did not serve as additional information. But the possibility of multispectral datasets will be very important for DSK within the near future, because DSK will be obliged to conduct large scale aerial surveys to provide CIR data sets for the monitoring of forests stands.

The work done so far shows a high accuracy and stability within the whole workflow. According to these results DSK will reduce the limitations for digital aerial camera flight campaigns from 30° sun elevation to 20° to enlarge the flight periods for the DEM generation in spring and possibly even in autumn. Further flight campaigns with digital aerial images will be assigned by DSK. The use of modified geometric and colour plates will be standardized and integrated in the photogrammetric workflow.

First investigations were made how those digital camera systems could be calibrated for further thematic analysis. The ideas developed so far were also promising and the development of a spectrometric process chain for the derivation of normed radiometric imagery is foreseeable.

7. REFERENCES

ASD: www.asdi.com

BLUH: Program System BLUH (BundLe Block Adjustment University of Hannover) www.ipi.uni-hannover.de/html/service/bluh/bluh.htm

GEOTEC: www.geotec.de

LPS: www.geosystems.de/produkte/photogrammetrie/

ORIMA: www.geosystems.de/produkte/photogrammetrie/lps-module.html

PRO600: www.geosystems.de/produkte/photogrammetrie/lps-module.html

RAL: www.ral.de/institut/en/index.html

SAPOS: www.sapos.de

WBF: www.weser-bildmessflug.de

GRUBER, M., PERKO, R., PONTICELLI, M. (2004): "The All Digital Photogrammetric Workflow: Redundancy And Robustness". In: Proceedings of XXth ISPRS Congress, July 12-23, 2004 Istanbul, Turkey, pp. 232-234.

KRÖPFL, M., KRUCK, E., GRUBER, M. (2004): "Geometric Calibration of The Digital Large Format Aerial Camera Ultracam". In: Proceedings of XXth ISPRS Congress, July 12-23, 2004 Istanbul, Turkey, pp. 42-44.

LEBERL, F. ET AL. (2003): "The UltraCam Large Format Aerial Digital Camera System". In: Proceedings of the American Society For Photogrammetry & Remote Sensing, May 5-9, 2003, Anchorage, Alaska

SMITH, G.M., MILTON, E. J. (1999): "The Use of Empirical Line Method to Calibrate Remotely Sensed Data to Reflectance". In: International Journal of Remote Sensing, 20, pp. 2653-2662, 1999.

SPRECKELS, V. (2003): "Subsidence determination by different sensor types using standardized transformation parameters". In Proceedings of ISPRS Joint Workshop of WG I/2,I/5 and IC WG II/IVand EARSeL Special Interest Group 3D Remote Sensing "High Resolution Mapping from Space", October 6-8, 2003, Hannover, Germany. On CD-ROM.