RMK D – A True Metric Medium-Format Digital Aerial Camera System

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ABSTRACT

A long history in the camera buisness is one important cornerstone to design high performing camera systems for airborne application and is the common basis for Carl Zeiss and Intergraph Z/I Imaging to develop RMK D, the next generation camera. This paper briefly reviews the past improvements of the Z/I sensor system and then presents the system concept for RMK D. The technical specification is highlighted and the optical system is described in detail. The concept and purpose of absolute radiometric camera calibration is discussed and finally results from a first test flight are presented.

1. INTRODUCTION

In July 2008 Intergraph Z/I Imaging announced RMK D as its new digital medium-format camera system. After the introduction of the DMC Digital Mapping Camera system in 2003, this is the base for the next generation camera system, positioned to address the growing demand for digital images and the needs of large and small companies for efficient data collection solutions.

Z/I has continuously invested in its solution for airborne data collection and data processing. Today, customers process data with the 6^{th} version of post-processing software and combine their aerial camera systems with high performing components, such as the ZI Inflight Flight Management System and the ZI Mount stabilized platform with MEMS sensors, which were brought to market in 2006 and 2008 respectively. The DMC camera system itself has proven to be a solid design; however the data storage peripherals have been updated twice since the initial version. The first change was the introduction of the FDS Flight Data Storage in 2005. This high performance, shock absorbing and hermetically sealed Data Storage System was still based on conventional hard disk technology and was subsequently replaced by a Solid State Disc (SSD) design. In 2007 this was the first SSD-based storage system for the commercial photogrammetric market and a remarkable advancement.

In the tradition of Carl Zeiss and Z/I Imaging to design robust and high performing systems for aerial camera users, RMK D follows rigid design principles and combines customized optics from Carl Zeiss with the newest sensor technology. Such tailored hardware solutions are necessary to withstand the rough conditions in an aircraft while making the camera a measuring system capable of delivering sustained high quality results.

Looking at the imaging market in general, we observed during the past years that high resolution satellite systems have encroached on the traditional market of aerial images. As of today GeoEye-1 or WorldView-2 offer images with ground resolutions of up to 0.5m. A further increase of resolution is proposed for GeoEye-2 to 0.25m and planned for 2011 for CartoSat-3 (0.35m). Vendors of digital cameras have equipped their aerial camera systems with NIR sensors and some, such as Z/I Imaging have successfully approached the market for classification with their products. To further improve the radiometric properties of their digital cameras, Z/I Imaging has investigated the possibilities to deliver image products which allow connecting the image digital number (DN) to radiance values to finally support absolute radiometry.

2. SYSTEM DESCRIPTION

RMK D is a medium-format camera and is positioned below the high resolution DMC to help customers to transition from analogue to digital. Available medium-format cameras often compromise in one or more areas such as frame size, color resolution of Bayer pattern CCDs, forward motion compensation, large GSD and field of view, geometric accuracy or system stability.

RMK D is designed to be a metric camera for geometry and radiometry and is the start of a new generation of sensors based on a flexible common platform. The new concept allows integration of one further sensor into the same platform.

Fig. 1: RMK D front plate - view from bottom with 4 MS camera heads, video camera (center) and space for additional sensor (left).

2.1. Technical Specification

From the photogrammetric point of view, RMK D can be classified as an intermediate angle camera, with 45mm focal length and a field of view of 49.5° across track and 54.2° along track. The large field of view results in an excellent Height to Base ratio of 2.4 which is unique for medium-format cameras and is still a valid quality indicator for 3D feature collection. The combination of 7.2 µm pixel and the 45mm focal length results in an image scale of 1: 11,111 delivering 8 cm GSD at an altitude of 500m (Table 1). The sensor has an effective size of 6096 x 6846 pixels. Since we have to consider manufacturing and assembly tolerances as well as TDI shifts the final image is cut to 5760 x 6400 pixels, which equates to an image size of 41.47 x 46.08 mm.

The camera is equipped with 2 integrated SSD cartridges to capture 2000 or optionally 4000 images. The weight of 56kg (with 2 SSD cartridges) qualifies RMK D for usage in small aircraft. Not only the weight but also the form factor of the RMK D is amazingly small. This can be mainly attributed to the modern Field Programmable Gate Array (FPGA) technique and the increase of complexity on the same size of silicon within electronic circuits (as an example, over the past 7 years storage density for D-RAM has increased by a factor of 16 on same silicon area).

The camera can operate up to an altitude of 8000m AMSL non-pressurized and is qualified for the temperature range from -20° - +40°C and therefore meets the requirement of the German standard 18740-4 (DIN, 2006) for aerial digital cameras.

Height AGL		Image Scale	GSD		Footprint	
[m]	*[ft]*		[m]	*[in]*	[m]	[ft]
500	*1640*	1:11111	0.08	*3.1*	512 x 461	1680 x 1512
1000	*3280*	1:22222	0.16	*6.3*	1024 x 922	*3360 x 3024*

Table 1: RMK D footprint and GSD for different altitudes.

One important requirement for the camera was to support high forward overlaps of up to 80%. To achieve this goal the camera can be operated in two modes selectable during runtime. The high quality readout mode allows a minimum 2 sec frame rate whereas a high speed readout mode will allow down to 1 sec cycle rate, depending on the solid state disk performance. Internally this is realized by reading the sensor from either one or two corners. With the high quality readout mode, the image information of the CCD is read out via one A/D converter, allowing highest radiometric uniformity at a lower frame rate. With the high speed readout mode, the image information of the CCD is read out via two A/D converters which doubles the cycle rate. The A/D converters are placed in one integrated circuit (= manufactured on one silicon wafer). This minimizes the amount of deviation between the A/D converters but results in slightly less uniformity. However, this effect will be perfectly compensated by the radiometric calibration.

2.2. Sensor System

The sensor system – the heart of RMK D – is the most important and complex part of the camera and the performance of each individual component has a direct impact on the final image quality. Optics, CCD and shutter are the three main components of the sensor system (Figure 2).

Fig. 2: RMK D – multi spectral camera head.

A very thorough design is required to make all the components work smoothly together and perform to their best. Not only does the MTF of the optics have to match the resolution of the CCD but also the influence of the filter on the optical path must be considered. Finally, the whole system has to perform within specification, even under extreme operating conditions.

2.2.1. Optics

The optics consists of a customized lens system, designed and manufactured by Carl Zeiss specifically for the RMK D. This design takes the shutter, the CCD with its optical front glass, and the filter, as well as the specified environmental operating range, into account (Doering, 2009) and has optimized the complete optical path from the cover glass to the sensor surface. This is a unique effort and as shown by Doering guarantees maximum image quality and hence clearly differentiates RMK D optics from other solutions available - especially from off the shelf optics.

The quality of the optics is measured as modulation transfer function (MTF) and the change of the MTF is an excellent indicator of stability under changing environmental conditions. The simulation on which the design is based showed that the MTF at half the Nyquist frequency will change only 12% with a drop in temperature of 40°K and will vary only 10% due to a change in air pressure corresponding to ΔH of 8000m. In comparison, the modulation transfer function of conventional optics will degrade 30% due to a variation in temperature of 40°K.

When comparing the performance of optical systems for aerial cameras it is important to take the real image height into account. In optics the image height is defined as the radial distance from the optical axis. To gain maximum performance the sensor must be inside the specified image height of the optics. For RMK D this is the case. The MTF is computed up to 35mm image height, the raw sensor (6846 x 6069 pixels) has an image height of 33mm however the image height of the final output image computes to 31mm only.

2.2.2. Sensor

The CCD is a 42 megapixel DALSA sensor (FT 53) developed exclusively for Z/I for Intergraph Z/I Imaging. The effective size is 6846 x 6069 pixels with an anti-blooming capability of 200 x full well capacity that is a factor 2 improvement over the DMC CCD. The sensor offers 70db dynamic range that computes [1] to 3162 DN or 11.6 bit effectively [2].

$$[1] \quad \begin{aligned} n\,[db] &= 20 \log DN \\ DN &= 10^{\frac{n\,[db]}{20}} \end{aligned}$$

n = dynamic range
DN = digital numbers

$$[2] \quad \begin{aligned} DN &= 2^b \\ b &= \frac{\log DN}{\log 2} \end{aligned}$$

b = effective number of bits per pixel

Attached to the CCD is a 14 bit A/D converter delivering grey values between 0 and 16383 to minimize the quantization errors.

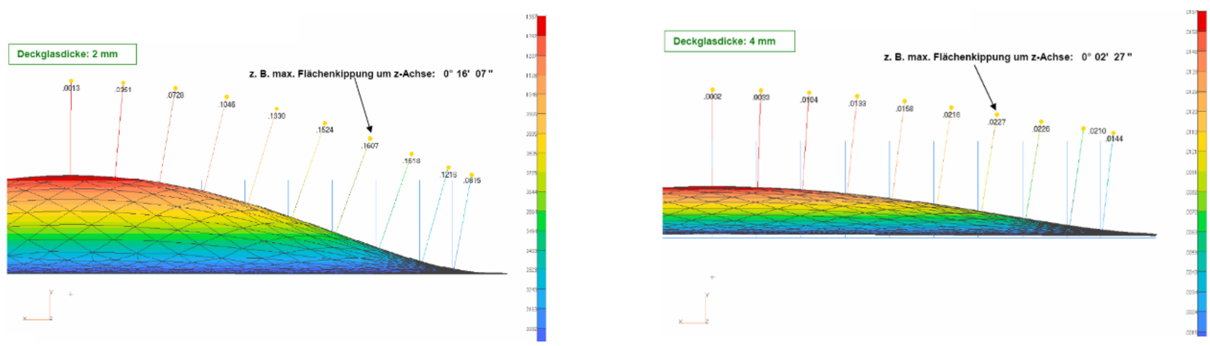

Fig. 3: (left) Deflection of a conventional 2 mm cover glass (max. tilt from z-axis 967)
(right) RMK D – deflection of 4 mm cover glass resulting in max. tilt from z-axis of 147”.

The CCD for RMK D is modified and sealed with a 4mm front glass to withstand changes in air pressure whereas the front glass on standard CCDs is only 1.4 mm thick. Figure 3 depicts the bending of a 4mm sensor cover glass exposed to a change in air pressure related to ΔH of 8000m. The deflection is reduced by a factor of 6 compared to a 2 mm cover glass.

2.2.3. Shutter

The Shutter represents the last remaining moving part in the digital camera and consists of 7 blades. DMC panchromatic camera heads are equipped with the same shutter. To guarantee constant behavior over the lifetime of app. 100,000 cycles, this device is equipped with a unique “non-aging” technique. During open and close cycles the actual position of the blades is measured with a frequency of 100 µsec. By using these sample values an internal real-time control algorithm adjusts for any mechanical deviation caused by temperature, pressure or humidity. By contrast, conventional electronic shutters are adjusted at the time of manufacturing with constant timing values and re-adjustment must take place in the factory. For the current image, these measurements are used to insert an aperture-dependent correction to make the image match the calibration situation. A correction technique was introduced into the PPS post processing software.

2.3. Radiometric Properties

The basic camera module consists of 4 nadir looking multispectral camera heads capturing the spectrum from 400 nm to 900 nm. The spectral bands are properly separated at the 50% point and fit to the perception of the human eye. For a quick characterization, the design values for the peak and 10% points are listed in Table 2.

	RMK D	
Band	Peak [nm]	10% Points [nm]
Blue	453	400-502
Green	525	482-591
Red	618	591-700
NIR	730	700-900

Table 2: RMK D - designed spectral response.

One of the main capabilities of RMK D is to deliver images for classification purposes - to supplement remotely sensed data or to allow delivery into the growing market for image data with absolutely-calibrated radiometry. After a stable geometry, this is the second main criteria of modern metric cameras.

To achieve this goal Intergraph Z/I Imaging has invested in a new integration sphere setup with calibrated spectral radiance. The new process for radiometric calibration is designed to fit into the workflow for current sensors and will also be introduced into the Post Processing Software for DMC and RMK D imagery. The new equipment is currently being tested. This new calibration aims to match the radiometric performance of remote sensing satellites (Ryan, 2009).

The absolute calibration not only improves the visual perception of images by better relative adjustment of the individual camera heads but also enhances radiometric uniformity across multiple cameras.

2.4. Data Processing

Image data post processing is based on the DMC Post Processing Software (PPS) and hence functions developed for users of the DMC large format camera will be available for RMK D users as well. However there are differences between processing DMC 12 bit images or RMK D 14 bit imagery. E.g. since TIFF JPEG compression is not defined for 14 bit images, users have to convert the 14 bit information to another bit depth or switch to JPEG 2000 compression. During post-processing the 3 additional multispectral channels are co-registered to the green image and cut to the final size of 6400 x 5760 pixels. Table 3 compares file size of a DMC image to an RMK D image.

	1 Band	**3 Band**	**4 Band**	**4 Band + OV**
DMC 7680 x 13824	202 MB	608 MB	810 MB	1.050 MB
RMK D 6400x5740	**71 MB**	**211 MB**	**288 MB**	**376 MB**

Table 3: File size - uncompressed image data 2 bytes/pixel,
4 band image with overviews.

During processing, the radiometric and geometric sensor calibration parameters such as flat fielding, shutter correction and lens distortion correction are applied. Processing of RMK D data will be slightly different; since the individual sensors are properly aligned, color balancing will become mainly a question of finding the best image data to screen conversion (14 bit to 8 / 10bit). To preserve the absolute radiometry of the images it is recommended to work with non destructive Look Up Tables (LUT) in future. ImageStation software introduced support for this method of data processing in release 6.0.

3. EARLY RESULTS

At the end of June, a test flight with the first Engineering Reference Model was executed near Cologne over an open mining area. Images were taken at 500 and 750m AGL resulting in 8 respectively 12 cm GSD. Due to a lack of time, not all camera heads were calibrated before the flight so the very first processing was performed using the calibration of the green camera head for all 4 bands. PPS software combines correlation and least squares matching to compute projective transformation parameters from the individual band to the reference image (green). Since we used 1 calibration for 3 bands we expected to see all errors of the macro lens system and from the camera assembly to appear as visible color fringes. The result is amazing – the only color fringes we could observe were in one corner of the image and the magnitude of this error was less than 2 pixels. This was a first, and very impressive, demonstration of the uniformity of the optical system.

3.1. Image Quality

To assess the final image quality we performed an edge analysis. Therefore an edge with a very high contrast was selected. Figure 4 shows the object and the selected edge where the measurement was performed. The edge appears in cross flight direction and is slightly tilted (app 8.3 deg) with respect to the pixel rows.

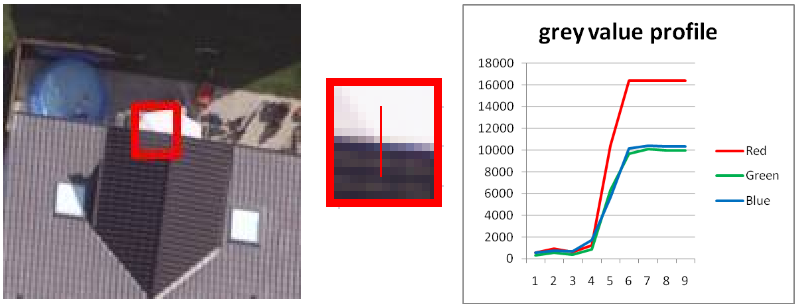

Fig. 4: (from left to right) Aerial Image (1st), selected object in 1:1 resolution (2nd), sampling line in magnification by factor 2 (3rd), grey value profile (right).

The edge is very sharp and proves the optical quality as well as the dynamic range of the sensors. Due to the tilt, the edge has to be mapped into 2 pixels and the profile shows the steep slope from pixel 4 to 6. In the bright area the response is very uniform at a level of app. 10000 DN. In the dark area we can see the structure of the roof tiles at app. 400 DN. The red channel in this picture is too hot and goes into saturation – settings for this camera head will be adjusted. The dynamic range in this scene is app. 9600 DN and still leaves enough room for information in very bright areas.

Figure 5 shows how the sensor behaves when going into saturation. This is a very important feature, since the blooming pattern (in this case due to specular reflection from the windscreen of a car) can destroy information in neighboring pixels. The pattern here is very limited; the center is only app 4x4 pixel which demonstrates the excellent anti blooming capability of the sensor.

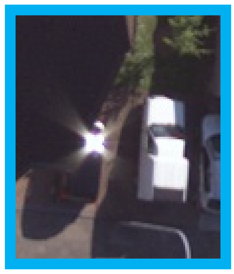

Fig. 5: Blooming.

3.2. Radiometric Calibration

An interesting test for the new absolute radiometric calibration is to demonstrate the efficiency of the aperture correction applied to flat fielding of images. This can be measured by mounting a DMC panchromatic camera head to the new integrating sphere and taking a series of 40 exposures, reading out the images and the shutter line to compute an aperture correction, and finally applying flat fielding to these images. The comparison of the signal-to-noise ratio gives an excellent measure for the improvement. Figure 6 shows the difference between flat fielding with (green) and without (blue) consideration of the aperture correction. The blue line shows the signal at 3110 DN. The RMS for this series was computed to 26.3 DN, resulting in a signal-to-noise ratio (SNR) of 118 or 0.84% noise. The green line shows the improvement of flat fielding with aperture correction. The signal is at 3210 and the noise was computed to 16.2 DN. This equates to a SNR of 198 or 0.5%. A very good result to achieve the typical goal for relative radiometry is to have less than 1% variation between pixels after flat fielding (Ryan, 2009).

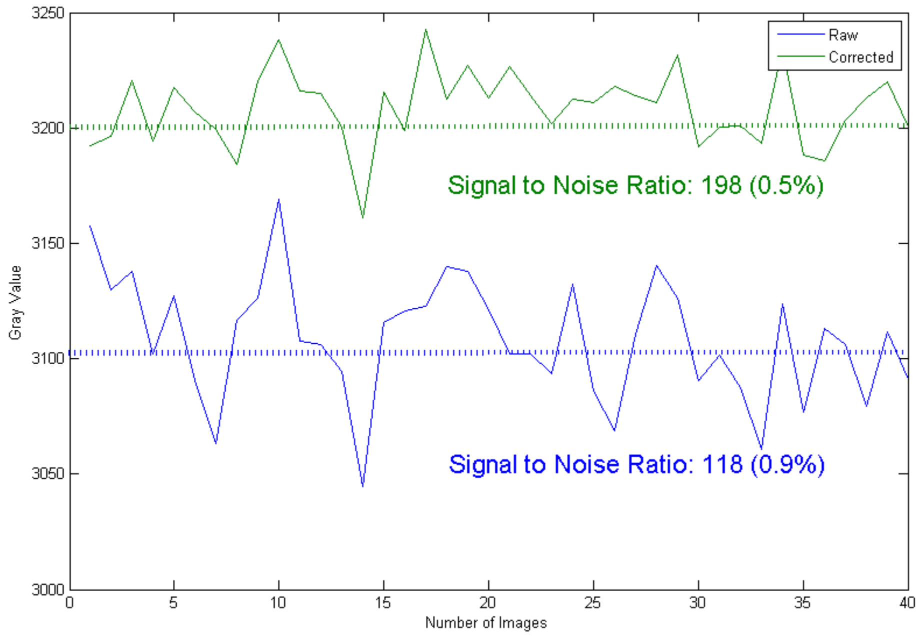

Fig. 6: SNR before and after aperture correction for 4.7 msec exposure time for a DMC image.

4. CONCLUSIONS AND OUTLOOK

Intergraph Z/I Imaging has developed a next generation camera system designed to meet the requirements of modern metric cameras. The first camera system was flown and the investigation of the results is ongoing. Data presented in this paper give a first real world proof of the outstanding sensor performance. Absolute radiometric system calibration, excellent optical properties as well as designed performance will help our customers to deliver high quality products.

5. REFERENCES

DIN 18740-4 (2006): Photogrammetrische Produkte – Teil 4: Anforderungen an digitale Luftbildkameras und an digitale Luftbilder, Beuth.

Doering, D., Hildebrand, J., Diete, N. (2009): Advantages of customized optical design for aerial survey cameras, in: Fritsch, D. (Ed.), Photogrammetric Week 2009, to be published.

Ryan, R., Pagnutti, M. (2009): Enhanced Absolute and Relative Radiometric Calibration for Digital Aerial Cameras, in: Fritsch, D. (Ed.), Photogrammetric Week 2009, to be published.